Columbia Environmental Research Center

Physical Aquatic Habitat Assessment, Fort Randall Segment of the Missouri River, Nebraska and South Dakota

By Caroline M. Elliott, Robert B. Jacobson, and Aaron J. DeLonay

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Altitude, as used in this report, refers to distance above the vertical datum.

Conventional Units: Scientists writing about U.S. rivers face a dilemma because the scientific community expects adherence to the System International (S.I.) units of measure whereas managers and the public relate almost exclusively to conventional and customary units of measure. Because of the importance of communicating results to stakeholders in the Missouri River basin, this report presents discharges in customarily used units of cubic feet per second, and river locations in terms of river miles. Depths, other horizontal dimensions, and velocities, however, are presented in S.I. units of meters and meters per second of centimeters per second. The conversion table above can be used to convert between units. River miles begin at 0 at the junction of the Missouri River with the Mississippi River at St. Louis, and increase in the upstream direction. Reference to left (L) and right (R) bank locations relate to direction while facing downstream.

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Abstract

This study addressed habitat availability and use by endangered pallid sturgeon (*Scaphirhynchus albus*) in the Fort Randall segment of the Missouri River. Physical aquatic habitat – depth, velocity, and substrate – was mapped in 15 sites in August and October of 2002. Habitat assessments were compared with fish locations using radio telemetry. Results indicate that pallid sturgeon preferentially use locations in the Fort Randall segment with deeper than the average available habitat, with prominent usage peaks at 3.5-4.0 m and 6-6.5 m, compared to the modal availability at 3-3.5 m. The fish use habitats with a modal velocity of 80 cm/s; the used velocities appear to be in proportion to their availability. Fish located preferentially over sand substrate and seemed to avoid mud and submerged vegetation.

Introduction

The endangered pallid sturgeon (*Scaphirhynchus albus*) is a riverine species found in turbid and deep rivers such as the Missouri and Mississippi. Biologists believe that pallid sturgeon habitat has been degraded on the mainstem Missouri River because of alteration of the natural hydrograph by reservoir management, and engineering of channel morphology (Dryer and Sandvold, 1993). Informed management of the Missouri River and the pallid sturgeon requires an understanding of quality and quantity of habitat, and how habitat varies over time and space (availability), and the habitat needs or preferences of the pallid sturgeon. One measure of habitat need is quantification of habitats where fish can be located (use), although it is understood that used habitats are not necessarily optimal, but may instead represent a preferred choice among non-optimal alternatives.

Physical aquatic habitat is generally defined as the combination of depth, velocity, and substrate that make up the space in which aquatic organisms live. Physical habitat varies spatially within a river channel and over time. Habitat varies over time in two ways: 1) at discharges below sediment transport thresholds, depths and velocities vary systematically as discharge varies, and 2) at discharges above sediment transport thresholds, channel geometry also can be altered, resulting in new combinations of depth, velocity, and substrate for a given discharge. The high spatial and temporal variation of physical habitat expected in the Missouri River present specific challenges to assessment of habitat and especially to assessment of habitat change. High spatial variability requires detailed mapping of physical characteristics at spatial scales relevant to fish use of habitat.

Hydroacoustic techniques and high-resolution global positioning system (GPS) georeferencing provide the tools to quantify the highly variable continuum of depth, velocity, and substrate on large rivers (Jacobson and others, 2002). Habitat mapping is an improvement over traditional point measures of habitat because it includes spatial variability. While these tools address questions relating to the quality, spatial extent, and spatial variability of habitat, they do not address temporal variability that results from changing discharge or geomorphic processes that alter channel morphology. Temporal variability can be quantified by monitoring or modeling habitats over a range of discharges, or – as in this study – ignoring temporal variation by focusing on a narrow range of index discharges.

The turbid, deep, and swift nature of the Missouri River also poses challenges to monitoring fish species. Traditional net-based sampling techniques are inadequate to answer specific questions about habitat use because of unknown biases in capture efficiency (DeLonay and Little, 2002). To counter these problems, fisheries biologists have developed telemetry techniques to collect intensive data on fish movement and habitat use (DeLonay and Little, 2002). This report presents results of a joint effort between the US Fish and Wildlife Service (USFWS) and the US Geological Survey (USGS) pairing hydroacoustic habitat mapping to assess habitat availability with telemetry to assess habitat use.

This study was conducted on the Missouri River between Fort Randall Dam and the headwaters of Lewis and Clark Lake (fig. 1). This segment is one of the few unchannelized riverine segments of the Missouri River and extends for 74 km below Fort Randall Dam on the Missouri River.

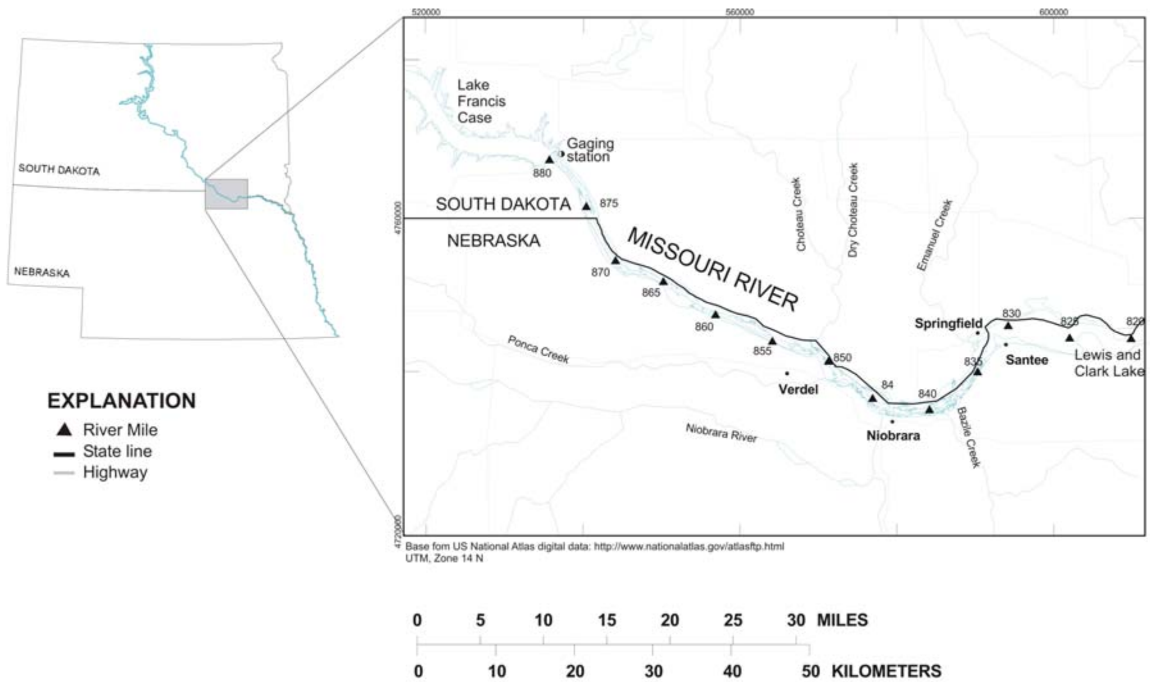


Figure 1. Map of the Missouri River study segment, located on the South Dakota - Nebraska border.

Purpose and Scope

This report documents methods and results of aquatic habitat assessment at pallid sturgeon relocation sites on the Missouri River below Fort Randall Dam. Only recently have studies addressed aquatic habitat depth, velocity, and substrate on the Missouri River (Jacobson and Laustrup, 2000, Jacobson and others, 2002). This study seeks to characterize physical habitat attributes at sites frequently used by pallid sturgeon in an unchannelized segment of the Missouri River. Our primary objectives were to quantify and provide maps of the depths, velocities, and bottom substrate of selected and non-selected pallid sturgeon habitat in the 74 km segment of the Missouri River. This project was a collaborative effort between the USFWS and the USGS.

The Fort Randall segment of the Missouri River is a remnant unchannelized length located between Lake Francis Case and Lewis and Clark Lake. This segment of the Missouri River displays a moderate to high degree of braiding with frequent sandbars and islands (fig.2). Channel widths in this 74 km of the Missouri River vary between 300 and 2,270 m with an average of 820 m (Biedenharn and others, 2001). High bluffs occur along most of the segment, and the channel is incised within banks 3-15 meters below the adjacent floodplain (Biedenharn and others, 2001). Below the Niobrara River the river becomes increasingly braided in the transition zone between the riverine portion of this segment and Lewis and Clark Lake.

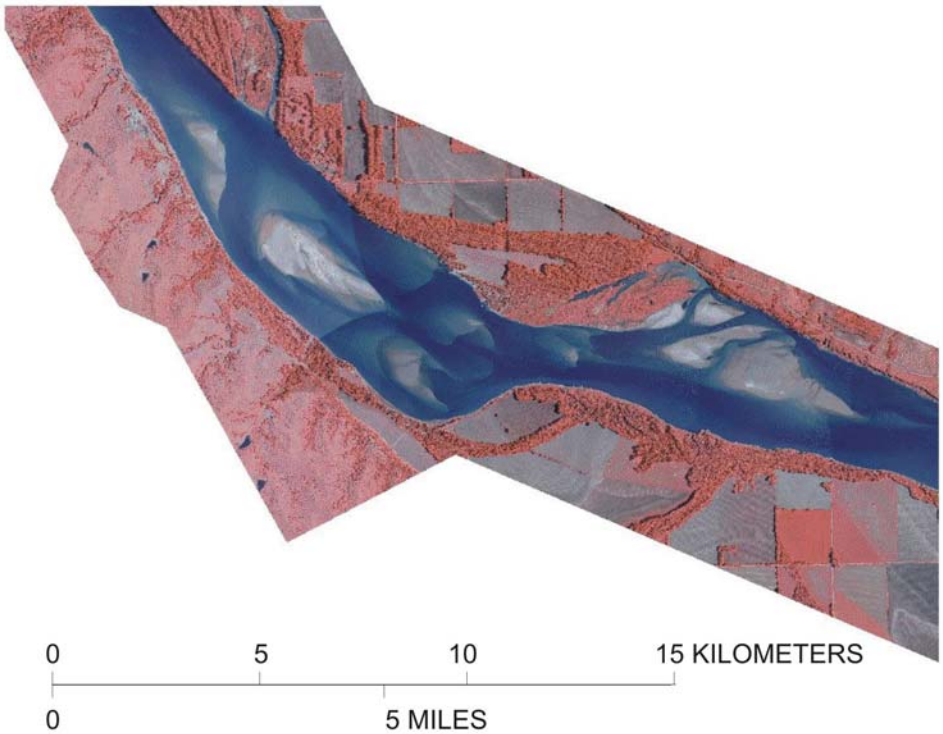


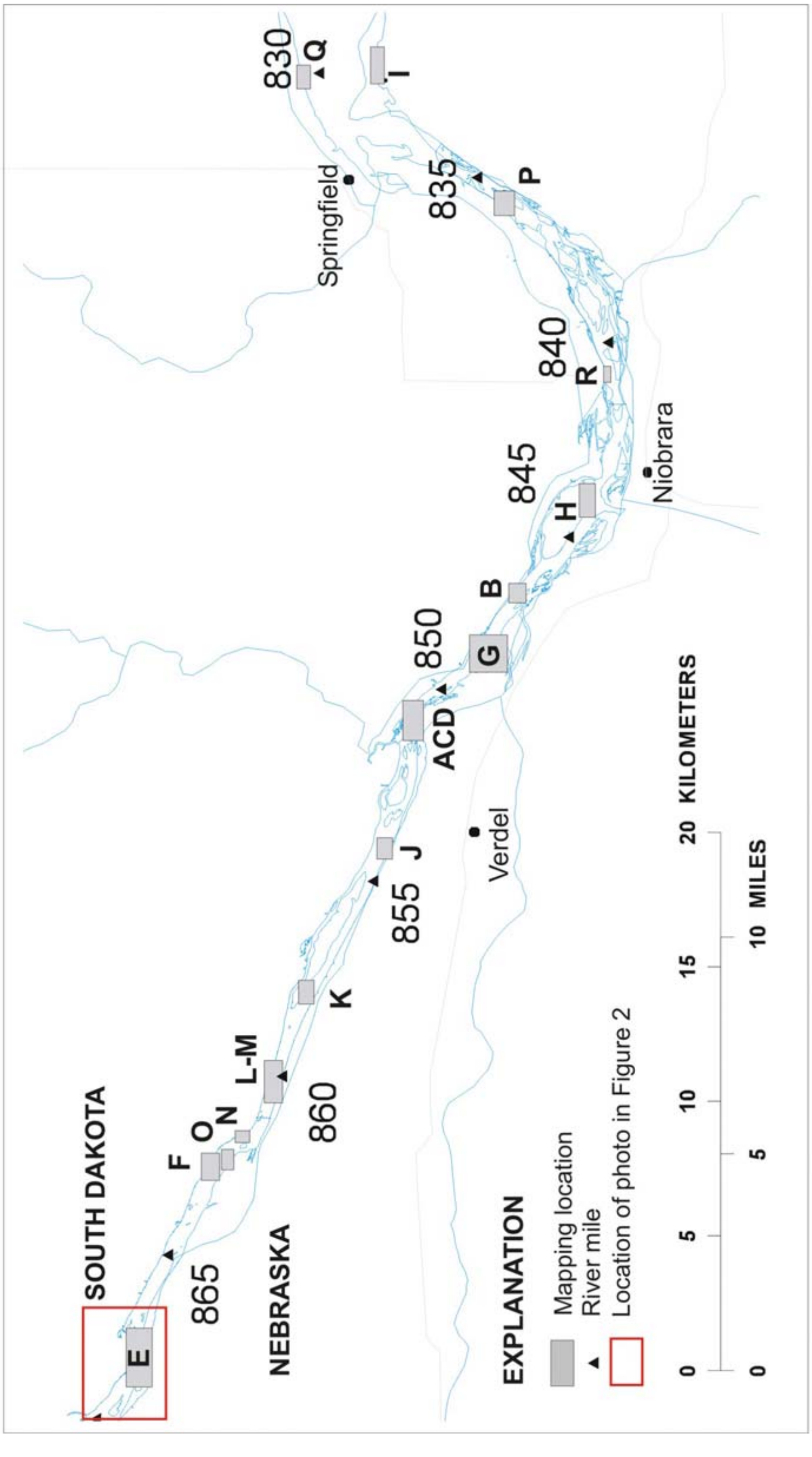
Figure 2. Aerial infrared imagery of a typical reach of the Fort Randall segment, Missouri River near RM 868, showing braid bars and islands.

Habitat use was assessed by characterizing regions around fish locations that were determined by USFWS (fig. 3). In 12 of 15 cases, habitats were mapped on the same or previous day of location. In the remaining three cases, habitats were mapped at locations where pallid sturgeon had been located frequently but were not present on the day when habitat was characterized. Regions were mapped during two seasons to capture seasonality of fish habitat use. Summer habitat was mapped August 6-8, 2003 with water temperatures 23 - 26 ^{o}C. Fall/winter habitat was characterized October 21-24 of 2002 in water temperatures between 9.4 - 19.1 ^{o}C. Regions were designed to encompass the range of used and non-used habitat patches surrounding fish locations. Mapped regions encompass habitat “patches” surrounding point fish locations approximately 200 m wide and 1000 m long.

Habitat assessments were performed in August 2002 and October 2002, at discharges ranging from 27,100 cubic feet per second (cfs) to 30,900 cfs (fig. 4, table 1). The August 2002 data were collected at discharges that are typically equaled or exceeded 75% of the time during late summer and the October 2002 data were collected at discharges equaled or exceeded about 50% of the time (fig. 5). River flows over the three-year telemetry period on this regulated segment ranged between approximately 2,500 and 35,000 cfs (Figure 4).

Acknowledgements

Harold E. Johnson, Mark Laustrup, and J. Alan Allert, U. S. Geological Survey, provided technical assistance in the field. Wayne Stancil, U. S. Fish and Wildlife Service and his technicians located sturgeon, and provided their fish telemetry locations.



Base fom US National Atlas digital data: http://www.nationalatlas.gov/atlasftp.html
UTM, Zone 14 N

Figure 3. Regions of habitat mapping between Ft. Randall Dam and Lewis and Clark Lake on Missouri River, Nebraska-South Dakota border. Letters represent habitat assessment sites.

Table 1. Information for habitat assessment sites

Site	River Mile	Survey Date	Missouri River Discharge	Pallid Sturgeon number
acd	851	8/7/2002	27,100	468
b	847	8/6/2002	27,200	263313
e	868	8/7/2002	27,100	356
f	863	8/7/2002	27,100	275
g	849	8/8/2002	25,900	
h	844	8/8/2002	30,900	
I	830	10/22/2002	30,900	213313
j	854	10/22/2002	30,900	468
k	858	10/22/2002	30,500	2345
l-m	860	10/23/2002	30,500	366 356
n	862	10/23/2002	30,500	446
o	862.5	10/23/2002	30,500	
p	836	10/24/2002	30,200	275
q	830	10/24/2002	30,220	213313
r	841	10/25/2002	27,600	

Discharge from Army Corps of Engineers gage at Ft Randall Dam
Pallid Sturgeon locations from US Fish and Wildlife Service telemetry study

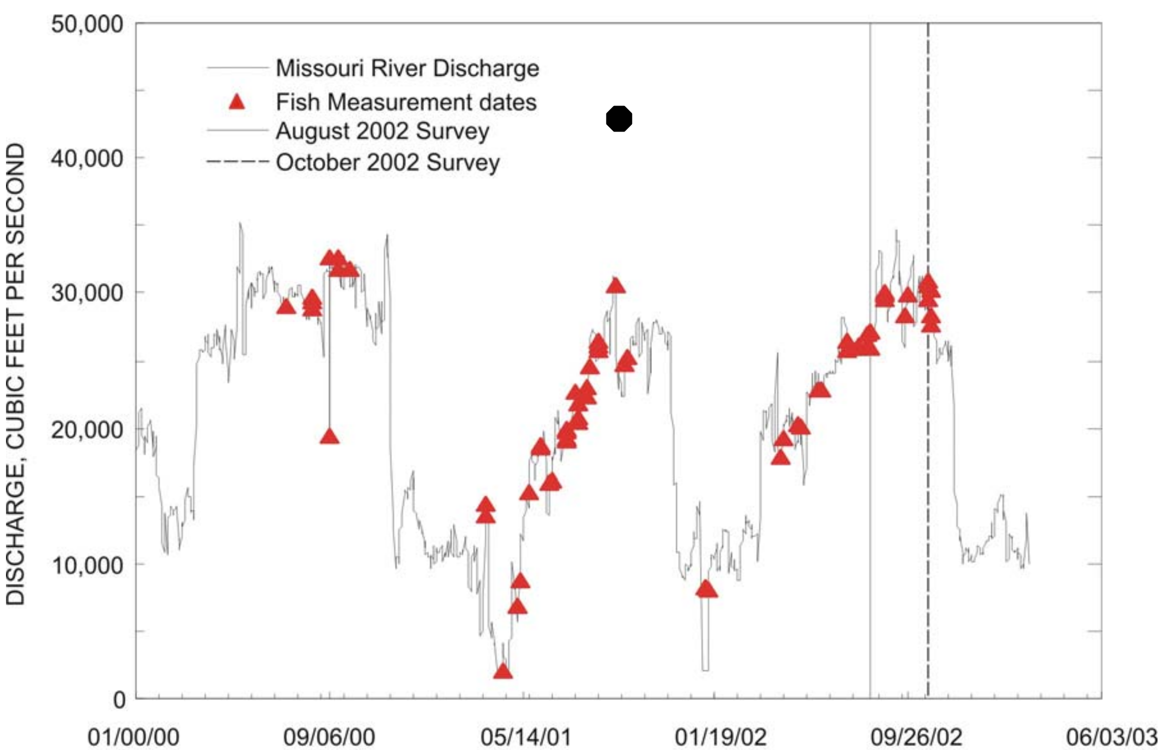


Figure 4. Daily mean discharge, Missouri River at Ft. Randall Dam, January 2000 to March 2003, and timing of habitat assessments.

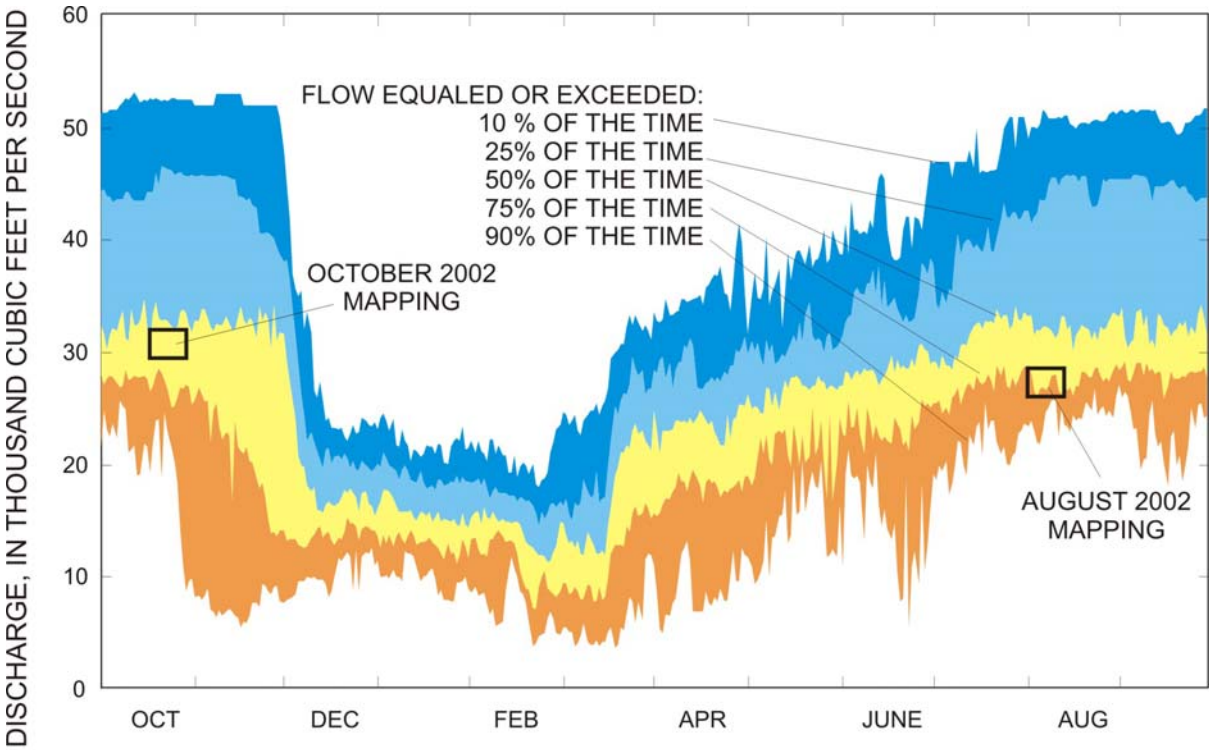


Figure 5. Discharge duration hydrograph showing the exceedance frequency of flow for each day of the year, calculated from historical Ft. Randall flow data, 1970 - 1998.

Methods

Fish location data were collected by USFWS biologists using standard methods (Stancil, 2003) described briefly below. Physical habitat data were collected and processed using protocols currently under development by the USGS at the Columbia Environmental Research Center (CERC); (figure 6).

Fish Locations

The USFWS released 6 adult and 22 juvenile hatchery raised pallid sturgeon in 2000 in the Missouri River near Verdel, Nebraska. The fish were implanted with sonic transmitters and passive integrated transponder (PIT) tags. Tags are expected to last approximately 36 months and tracking has continued from release through the fall of 2002 (Stancil, 2003). The power supplies on these tags were expected to last though early winter of 2002-2003.

Fish were relocated using an ultrasonic receiver and directional hydrophone. Fish locations were recorded when impulses were equally audible with a 360 degree rotation of a hydrophone. At this point, the fish's location was recorded using a global positioning system (GPS), resulting in a total positional accuracy of about +/- 15 m. Additional USFWS point data included depth, surface water temperature, bottom velocity, and turbidity.

Fish were relocated by the USFWS twice a month using both extensive and intensive tracking. Extensive tracking involved relocating as many fish as possible during a tracking period. Intensive tracking required relocating an individual fish at regular intervals over a 2-3 day tracking period to get an idea of the movements and selected habitats of individuals. Results from USFWS data suggest that seasonal fish movement is substantial (Stancil, 2003). Therefore an effort was made to map fish habitats associated with summer habitat in August, and late fall/ winter habitat in October.

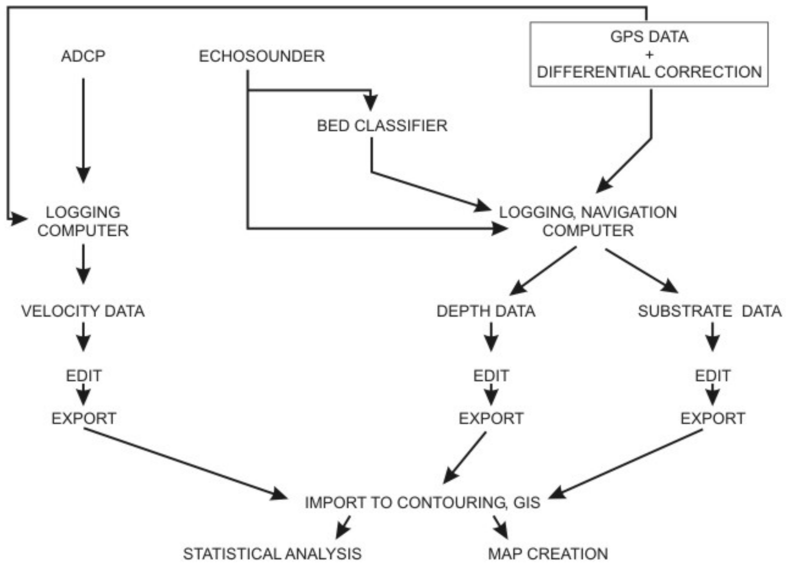


Figure 6. Schematic diagram of habitat assessment data collection and processing. ADCP, acoustic Doppler current profiler; GPS, global positioning system; GIS, geographic information system.

Habitat Assessment Data Collection

Navigation base maps of the Missouri River channel were created by digitizing the edge of water visible in 1999 using orthorectified aerial photography acquired at discharge of about 9,000 cfs (USACE, pers. comm.). These digital maps were exported as georeferenced DXF files and imported into HyPack ® (Coastal Oceanographics, Middlefield, Connecticut)[1] navigation software. The digital maps were used as base maps for transect design and field data collection in HyPack. Sampling transects were constructed to cover all areas of interest surrounding fish relocation sites using transect layout routines in HyPack. Sampling transects were generated at 20-m spacing and oriented generally perpendicular to the channel thalweg (fig. 7). The prospective mapping area extended well beyond the immediate fish location to ensure representative sampling of habitat availability in the river. The 20-m spacing was chosen to provide sufficient spatial coverage for creating continuous surface maps of depth and substrate data given usual scales of variation of these characteristics. Transects ended laterally when the depth became too shallow for the boat to survey, at approximately 0.75 m.

[1] Product names are provided for information purposes only and do not constitute and endorsement by the U.S. Geological Survey

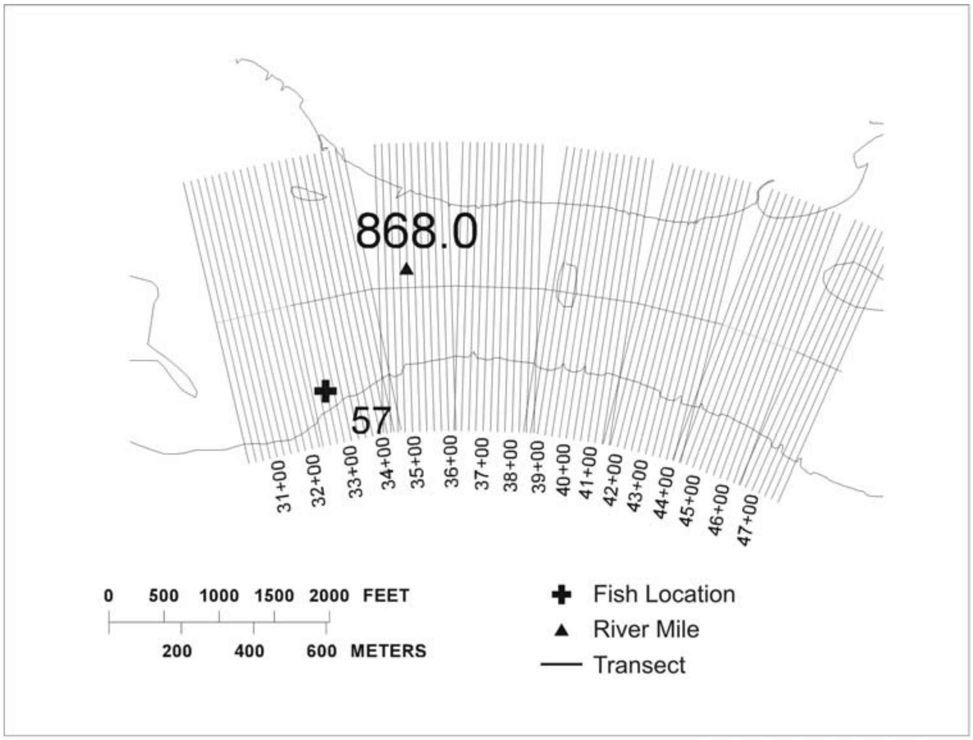


Figure 7. Typical arrangement of sampling transects at site e, RM 868, for bathymetric data collected on August 7, 2002.

All data were georeferenced in the field by a real-time, 12-channel differential global positioning system (DGPS) to sub-meter accuracy. Differential corrections were applied in real time by the Omnistar ® (Omnistar Inc., Houston, Texas) satellite-based system. The satellite based corrections had estimated to result in positional errors of 0.6 – 1.0 m, 1 SD. The DGPS data were collected at 200 millisecond (ms) intervals, resulting in positions approximately every 0.3 – 3.0 m along each transect at typical boat speeds of 2 – 8 knots, or 1-4 meters per second (m/s) during data collection. Boat speeds were maintained at 5 knots or less most of the time.

Bathymetric data were collected with a Hydrotrac ® echo sounder (Odom Hydrographic Systems, Inc, Baton Rouge, Louisiana) equipped with a 208 kilohertz (kHz), 8^{o} transducer mounted over-the-side of the boat (fig. 8). Positions were corrected for the offset from the DGPS antenna. The echo sounder was calibrated by bar check to account for boat draft, blanking distance (minimum distance required for sound waves to return), and environmental conditions (such as temperature and turbidity) that could affect the speed of sound in water. The bar check is a calibration procedure based on suspending a metal plate at known depths below the transducer. Pitch and heave were not compensated and large waves that existed during some of the mapping had measurable effects on depths. The effect of pitch and heave were largely removed from the dataset, however, by data smoothing in the process of creating continuous-surface maps (see Data Processing section). The precision of the echosounder data is 0.03 m. Bar check results indicate that, under favorable bottom conditions, the depth accuracy is approximately 0.07 m.

Bed material was classified into substrate classes using a RoxAnn ® system (Stenmar Marine Microsystems, Aberdeen, Scotland), which uses the transducer output from the Hydrotrac system. The RoxAnn analyzes the shape of the acoustic signal returned from the river bottom to calculate two parameters related to roughness and hardness (e_1 and e_2); (see, for example, Rukavina, 1997). Depth, bed-material classification, and DGPS positions were logged into standardized HyPack files.

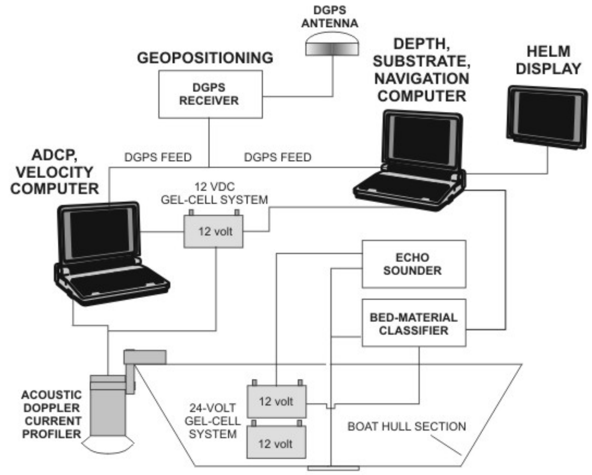


Figure 8. The RV Slim Funk (USGS Habitat assessment boat), and data collection schematic. DGPS, differential global positioning system; ADCP, acoustic Doppler current profiler.

Velocity data were collected with a Workhorse Rio Grande Model ® 600 kHz acoustic Doppler current profiler (ADCP) and logged in WinRiver software (RD Instruments, San Diego, California). These data were also georeferenced with DGPS data, but were collected on a separate laptop computer (fig. 8) running the WinRiver ADCP acquisition program. The ADCP was set up to collect 3-dimensional water velocity data in 0.35-m deep bins from the surface to the bottom following the setup and operation procedures (Morlock, 1996). A column of bins (called an ensemble) was collected nominally every 2.5 seconds, resulting in an ensemble spacing that varied from approximately 2.5 – 10 m at typical boat speeds. For ADCP data collection, boat speeds were maintained below 5 knots, resulting in a maximum ensemble spacing of about 3.8 m. The ADCP was internally calibrated for measured water temperature and compensates automatically for pitch and roll. A typical velocity profile transect is illustrated in fig. 9.

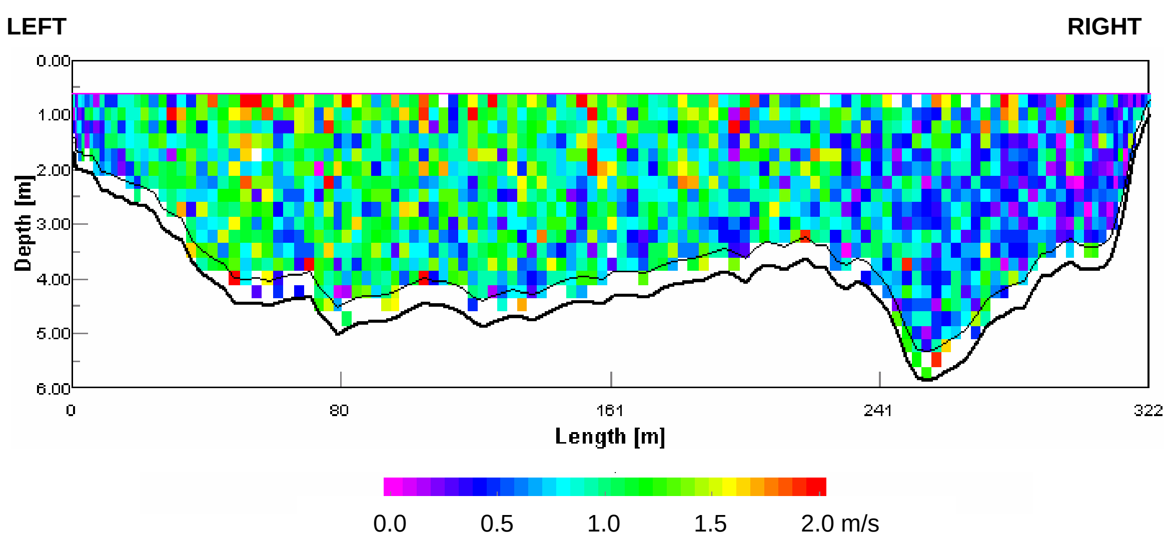


Figure 9. Acoustic Doppler current profiler transect showing distribution of velocities in a vertical plane, from August 2003 assessment, at site ACD at RM 851. Transect is viewed looking downstream and current velocity is projected into the plane of the section, in m/s.

Limited surveys were also conducted at each site using high-frequency sidescan sonar. Sidescan surveys were conducted using a SeaScan® PC system developed by Marine Sonic Technology, LTD. The SeaScan® PC is a high-frequency, high-resolution sonar imaging system capable of operating at frequencies ranging from 100 kHz to 2400 kHz depending upon the towfish and transducers selected. Surveys conducted for this study used a towfish operating at 900 kHz. High frequencies provide images of greater resolution. However, higher frequencies attenuate quickly in turbid water and effective range is markedly reduced. In addition, high-resolution systems are adversely affected by erratic towfish motion caused by river currents, turbulence or changes in direction of the survey vessel. The 900 kHz operating frequency has proven to be an effective compromise for imaging habitat features of importance at the scale of the individual fish under conditions prevalent in large rivers.

The sidescan sonar system operates by utilizing two side-looking transducers on a towed-body, or towfish, which is pulled along just above the bottom by the survey vessel. The sonar system was controlled through a ruggedized field computer and was connected to a differential GPS system using a commercial satellite-based differential correction receiver (fig 10). Differential GPS data provided submeter horizontal positioning, and is used both to georeference the sonar record and to control the sampling rate of the sonar. The transducers continuously emit a narrowly focused beam of sound perpendicular to the direction of the towed body and the vessel (fig 11). The pulses of acoustic energy passed through the water and along the bottom. Some of the energy was reflected off of the bottom substrate or other objects on the bottom or in the water column. This reflected acoustic energy (backscatter) was detected by the towfish and the strength of these signals is recorded by the sonar system. The system then builds a continuous image of the bottom, line-by-line, using the backscatter information. Acoustic backscatter data was recorded directly to the hard drive of the portable computer. During the survey the sonar record was parsed into discrete sonar images at 1000 scan-line intervals.

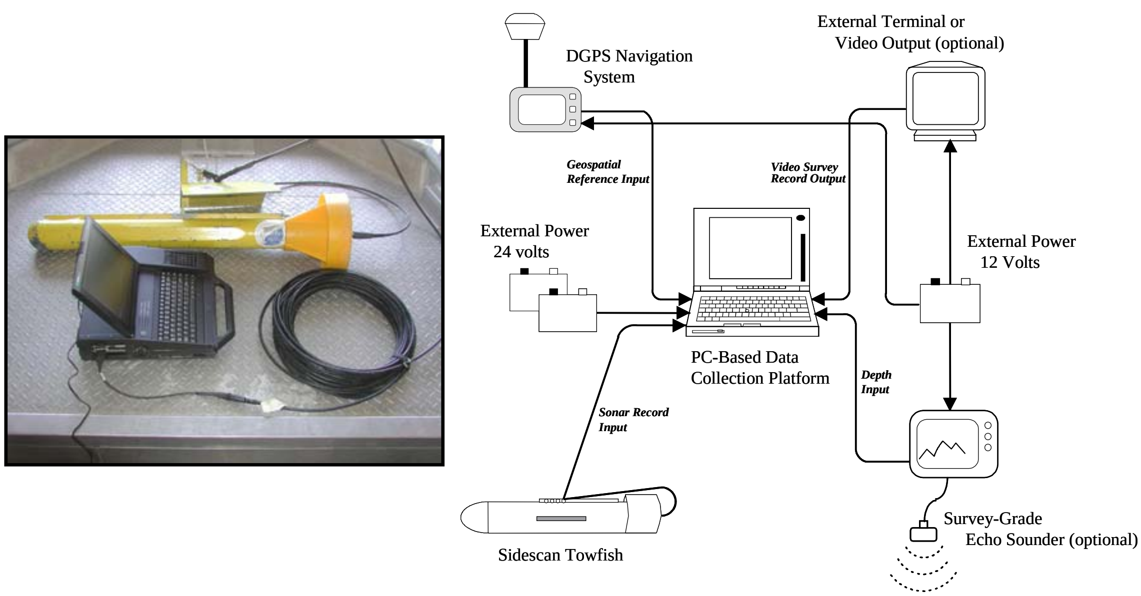


Figure 10. SeaScan® PC sidescan system, and sonar imagery collection schematic. DGPS, differential global positioning system.

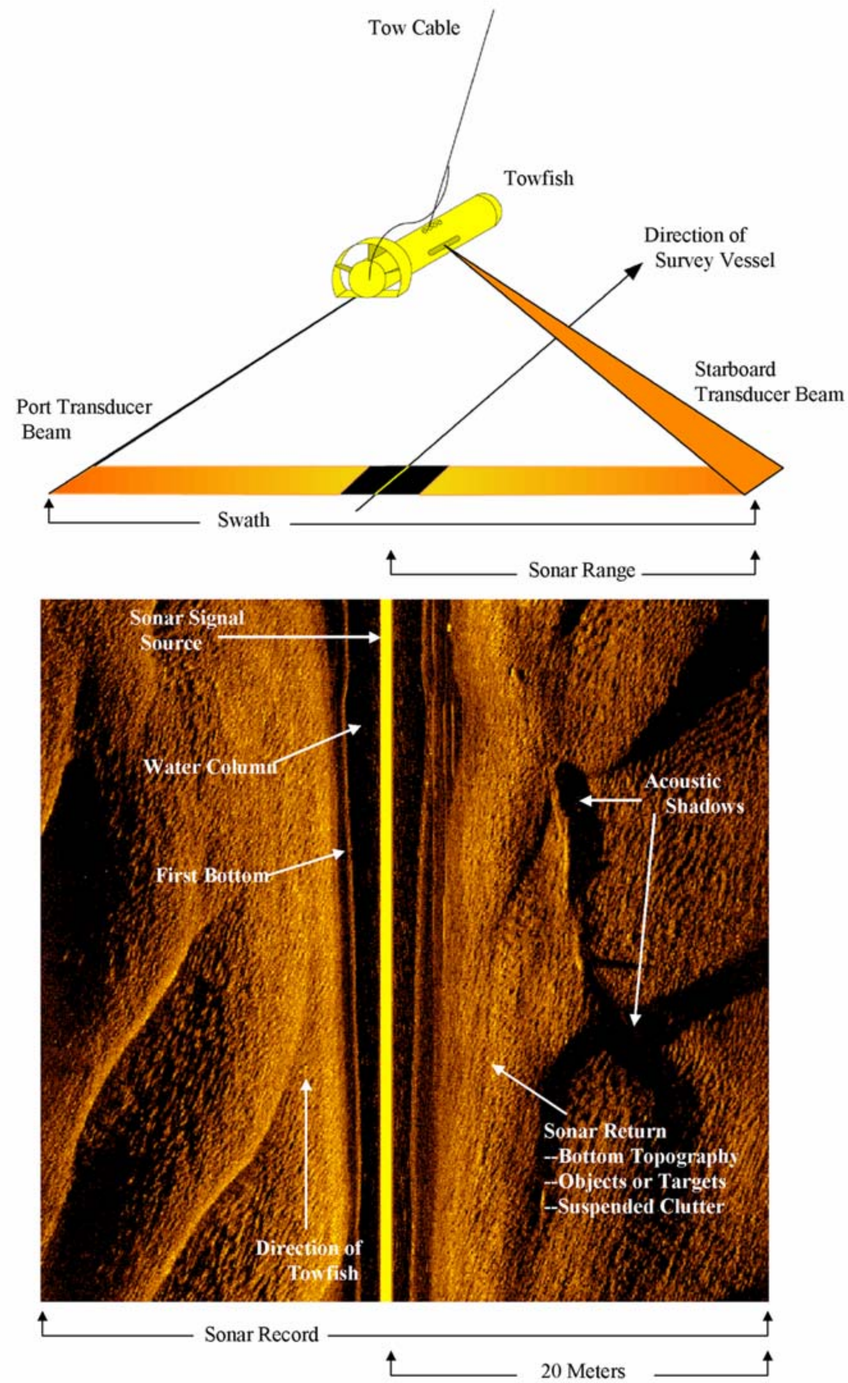


Figure 11. Sidescan system in operation and illustration of a typical sonar record. The towfish was pulled through the water and the system emits narrow beams of acoustic energy perpendicular to the direction of towfish travel. The acoustic energy reflected off the bottom was recorded and a sonar image was constructed line-by-line

Data Processing

Bathymetry

Several pre-processing steps were required prior to generating continuous surfaces for the bathymetric datasets. Depth data were edited using a routine included with HyPack. Typically, editing was required to remove spurious reflections from water-column turbulence, vegetation, or fish and to correct for places where bottom conditions prevented a good digitization (fig. 12). Also, the DGPS signal occasionally dropped out where high banks or trees interfered with satellite reception, thereby creating incorrect positions. The high data input rates allowed spurious depths to be deleted without affecting the representation of bottom contours. In some places, substantial areas of spurious depths could be corrected by reference to depths digitized by the RoxAnn unit, or recorded from the ADCP, and the echo sounder paper trace. Positioning errors because of DGPS dropout were often corrected in HyPack by linearly interpolating positions relative to adjacent correct positions. Following editing for accuracy and content, the datasets were exported from HyPack as comma-delimited files containing data of UTM northing and easting, depth, and substrate for each data point.

A PERL script (Practical Extraction and Report Language, ActiveState Corporation, Vancouver, British Columbia), was used to edit, format, and prepare the comma-delimited files for grid creation. Surfaces were interpolated using Surfer 7 ® (Golden Software, Inc., Golden Colorado) by kriging, which is a standard surface interpolation method. A four quadrant elliptical search with a radii of 50 x 30 meters was used against the 20-meter spacing of transects. Spurious data points were eliminated from consideration and the output grid resolution was set to 5-meter. A blanking file was then used to clip the interpolated grid to the extent of the input data set.

The Surfer 7 grids were exported as ASCII files and then added to an ArcView ® (version 3.3, Environmental Systems Research Institute, Inc, Redlands, California) project as a table. Each table was added to a view as a point event theme and converted to a 5-m grid.

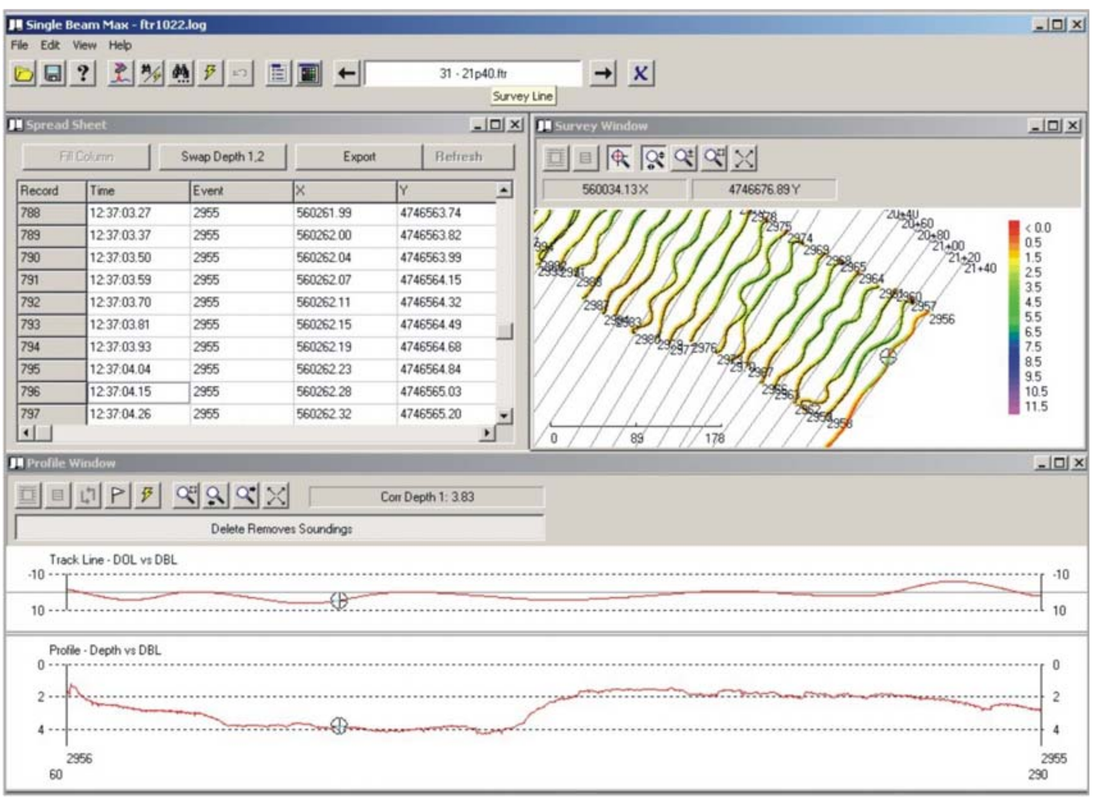


Figure 12. Edit screen from Hypack. Top right hand corner shows the track lines and raw depth points. Top red line (track line) shows boat position relative to planned transect. The bottom line is the digitized depth trace. Spurious depth spikes are deleted and interpolated in this edit step.

Substrate

Raw substrate roughness (e1) and hardness (e2) values were exported from HyPack. A PERL script was used to transform the raw e1 and e2 values by taking the square root and multiplying by 100. The resulting integer values for roughness (e_1) and hardness (e_2) were imported into Surfer 7 for surface interpolation. These files were also clipped with a blanking file, and imported as event themes and converted to 5-m grids in ArcView.

Grids for roughness, hardness, and depth were classified into substrate classes using a multivariate unsupervised classification routine in ArcInfo ® (version 8.3, Environmental Systems Research Institute, Inc., Redlands, California). Depth was included in the substrate classification because the area of the river bed that an acoustic signal interacts with changes with depth. Therefore the roughness values for a given substrate may appear to change with depth because of unique features of the sample area. The multivariate classification of roughness, hardness, and depth isolated clusters of data with similar e1, e2, and depth values (fig. 13). Four distinct classes were classified through unsupervised classification (Fig. 13). The apparently overlapping classes separate when third dimension, depth, is included. Interpretation of this classification matrix was aided by analysis of sidescan sonar data, and comparison to other data sets specific to the echo sounder/transducer system and to the bottom conditions of the Missouri River.

Velocity

Data collected using ADCP were exported from WinRiver as ASCII-formatted files and reformatted with a PERL script for import into ArcView. The velocity magnitude, horizontal velocity direction, vertical velocity component, and position (easting, northing, and depth) were extracted for each individual bin during this reformatting step. A PERL script also calculated the depth-average velocity for each ensemble (vertical collection of data).

These data were subsequently imported into ArcView for 2-dimensional (2D) visualization. Mean velocity data was imported to Surfer 7, which interpolated data by kriging into 5-m intervals. The data were clipped with a blanking file, imported in ArcView as an event theme and grids of mean velocity were produced with a 5-m cell size.

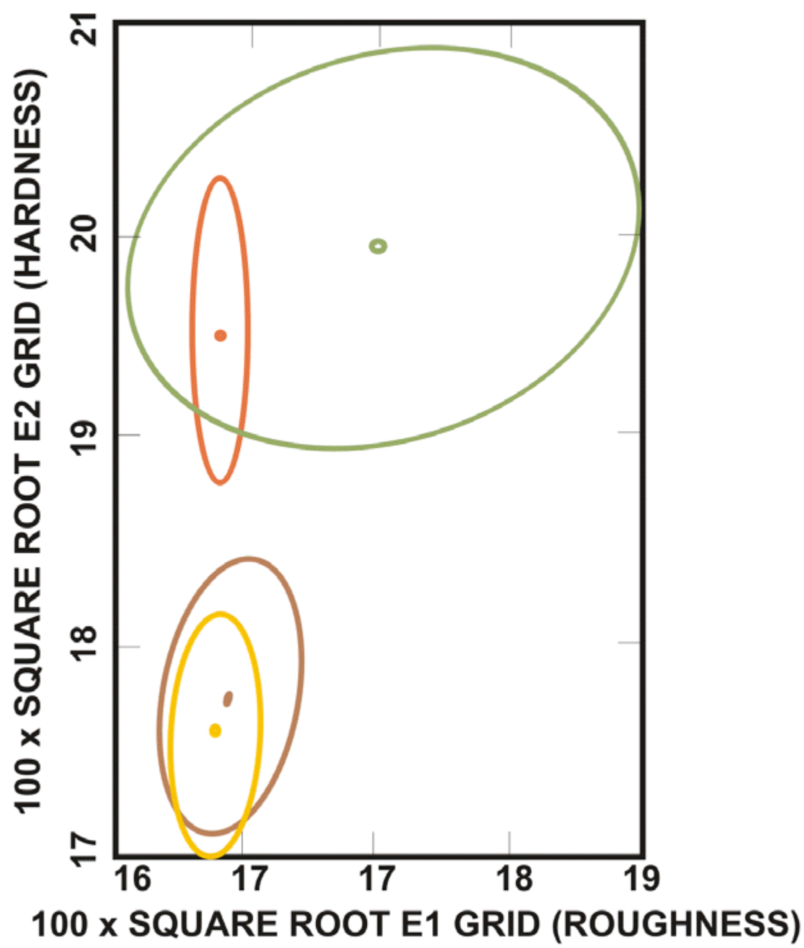


Figure 13. Data clusters produced by a classification of substrate variables E1(roughness) and E2(hardness). The depth dimension is not displayed on this graph.

Sidescan Sonar

Each sonar image was saved as a georeferenced 256 color, 8-bit TIFF image. Post-processing was accomplished using SonarWeb ® software (Chesapeake Technology, Inc., Mountain View, California.). Post-processing included correcting the image for true navigation, bottom detection and tracking, removal of the water column, and slant range correction. Only navigational correction was required for creating a mosaic of individual images together in sequence. At the ranges and resolutions used in this study, navigational correction was sufficient to produce quality images. Additional corrective post-processing was not always desirable in shallow water habitats with diverse bottom types and a high number of small targets. It could have resulted in the significant loss of detail that may be of interest to investigators.

Aquatic Habitats, Fort Randall Segment

Results of the fifteen habitat assessments are shown on maps in ArcView maps (Appendix 1) that are arranged by site and RM. Maps of depth, mean velocity, and substrate are also included in appendix 1, along with pallid sturgeon locations. Fish present during the habitat assessment were labeled with their code number and locations where the fish had been found during the entire 2-year duration of the study are also plotted. Depths and velocities by assessment site are summarized in Table 2.

Depth

Mapped regions of available habitat within the Fort Randall study segment had depths ranging from 0 to 12.8 meters. Histograms were created to illustrate depth ranges at individual sites binned by 0.5-meter depth class for all mapped sites in this study (fig. 14). For comparison to available habitat, the distribution of all mapped habitat was plotted with individual site data. The mean depth for the entire study region was 3.56 meters. Means by site vary, but ranged between 2.37 and 5.63 meters (table 2).

Deeper regions were associated with the main channel and thalweg locations. The deepest region mapped (12.8 m) is a scour hole at Site B, RM 847 associated with an irrigation pump intake. This site had deeper than average depths compared to the segment overall (fig 14). Shallower depths were associated with shoreline, channel and island margins, and large sandbars. For instance, the large sandbar mapped at site E, RM 858 was associated with shallower than average depths (fig. 14).

Pallid sturgeon habitat use was determined by comparing USFWS telemetry results with USGS habitat assessment maps. Tagged fish were present at twelve mapped locations during the August and October 2002 habitat assessments. Their locations and habitat uses were summarized by site and RM (table 3). Both the USFWS point measurements as well as USGS point depths produced by habitat assessment results of this study were evaluated. Depths indicated were depths of water at the fish location; although these are not necessarily equivalent to the depths occupied by the fish, pallid sturgeon are generally thought to spend most of their time at or very near the bottom of the river (Dryer and Sandvol, 1993). Differences in USGS and USFWS depth and velocity values result from the differences in scale and positional accuracy. Sonic telemetry methods and uncorrected GPS measurements located fish in a region often 10-20 m in diameter that may have encompassed a variety of depths and velocities. USFWS biologists took depth and velocity data at one point within that area. Bed depths, rather than fish depths were measured because the USFWS equipment used in this study does not allow biologists to locate the elevation of the fish within the water column. The USFWS also obtained velocities at the bottom, 0.2 percent, and 0.8 percent depths. The average of these values would be expected to be less than the depth-averaged velocities calculated in the USGS dataset.

Average depths of fish locations calculated were derived from analysis of 5-meter scale habitat grids that were compared with USFWS telemetry coordinates (table 3). Each fish location was paired with the depth value of the single 5-m grid cell from which it was collected. Within the USGS dataset, these fish were located at an average depth of 4.34 m. This selected depth was 0.78 m deeper than the mean available depth of 3.56 m. Individual depths by site are indicated on the histograms of available depth in figure 14. For instance, at site ACD, RM 851, fish 468 used shallower water than most of the available habitat in the region adjacent to the fish's location. In sites I and P, RM 830 and 836, fish 213313 and 275 used deeper habitat than that available nearby.

Point measurements at each fish location varied considerably. Depths in the mapped areas changed as much as 8 m vertically over 15 meters horizontally. Thus, habitat maps provided a substantial increase in ability to assess habitat use and availability relative to point measurements. In addition, maps can allow assessment of use and availability at different spatial scales by varying the patch size associated with individual fish locations (Jacobson and others, 2002). Although not implemented in the current study, this method can be used to account for home-range effects related to high-frequency fish movement.

Table 2. Means, ranges, and standard deviation of vertically averaged current velocities and depths summarized by assessment site. (cm, centimeters, Min., minimum; Max., maximum; Std. Dev., standard deviation)

	Depth, meters				Current velocity, cm per second			
Site	Mean	Min	Max	Std. Dev.	Mean	Min	Max	Std. Dev.
ACD	4.49	0.69	11.14	2.18	73.0	0	144.75	17.85
B	5.63	0.85	12.82	2.41	73.33	2.43	168.85	14.79
E	2.75	0.52	7.21	1.44	80.24	2.59	203.04	26.99
F	4.39	0.49	8.05	1.75	92.10	0.38	179.49	21.53
G	3.84	0.74	7.53	1.74	71.00	0.20	165.80	19.45
H	3.84	0.36	11.3	1.84	88.05	0	157.86	21.81
I	3.81	0.22	8.16	1.57	88.56	0	187.47	21.73
J	2.37	0.82	4.59	0.86	70.17	9.94	186.39	30.35
K	2.67	0.70	4.36	0.76	101.19	0	251.69	31.61
LM	2.86	0.75	5.10	0.97	68.70	0.40	252.56	36.70
N	4.19	0.91	8.14	0.91	76.26	0.21	159.89	21.89
O	3.70	0.98	8.14	1.4	92.42	0	201.28	20.42
P	3.15	0.92	7.93	1.56	85.80	0	202.6	27.38
Q	3.18	0.88	4.66	0.54	70.78	0	126.85	16.02
R	3.91	0.89	6.58	1.33	99.54	0.26	181.06	29.05

All telemetry data collected since implantation and release in 2000, including intensive and extensive tracking data, was compiled to create a larger data set of pallid sturgeon habitat use. Only measurements taken at comparable discharges (between 20,000 and 32,000 cfs; fig. 4) were included in this analysis. These results indicate that pallid sturgeon in the Fort Randall segment are, on average, using deeper habitat than that available, indicating preferential use (fig. 15).

Table 3. Point habitat data for pallid sturgeon at assessment sites: USGS data calculated from habitat assessment grids

Site	River Mile	Survey Date	Pallid Sturgeon number(s)	Pallid point depth, meters (USFWS)	Bed depth at pallid location echotrac data, meters (USGS)	Velocity at .2 and .8 depths averaged, centimeters per second (USFWS)	Average velocity centimeters per second, Doppler data (USGS)
ACD	851	8/7/2002	468	4.8	2.6	17	72
B	847	8/6/2002	263313	5.6	6.5	84	89
E	868	8/7/2002	356	4.2	3.5	96	60
F	863	8/7/2002	275	4.4	4.6	44	67
G	849	8/8/2002					
H	844	8/8/2002					
I	830	10/22/2002	213313	6.9	7.3	108	95
J	854	10/22/2002	468	2.6	3.4	58	83
K	858	10/22/2002	2345	2.3	3.3	60	123
L-M	860	10/23/2002	366, 356	4.0/3.0	4.2/2.2	94/80	101/110
N	862	10/23/2002	446	4.8	5.5		88
O	862.5	10/23/2002					
P	836	10/24/2002	275	5.8	5.6	69	88
Q	830	10/24/2002	213313	3.6	3.4	71	75
R	841	10/25/2002					

Pallid sturgeon locations, depths, and velocities from US Fish and Wildlife Service telemetry study (Wayne Stancil, pers. comm.).

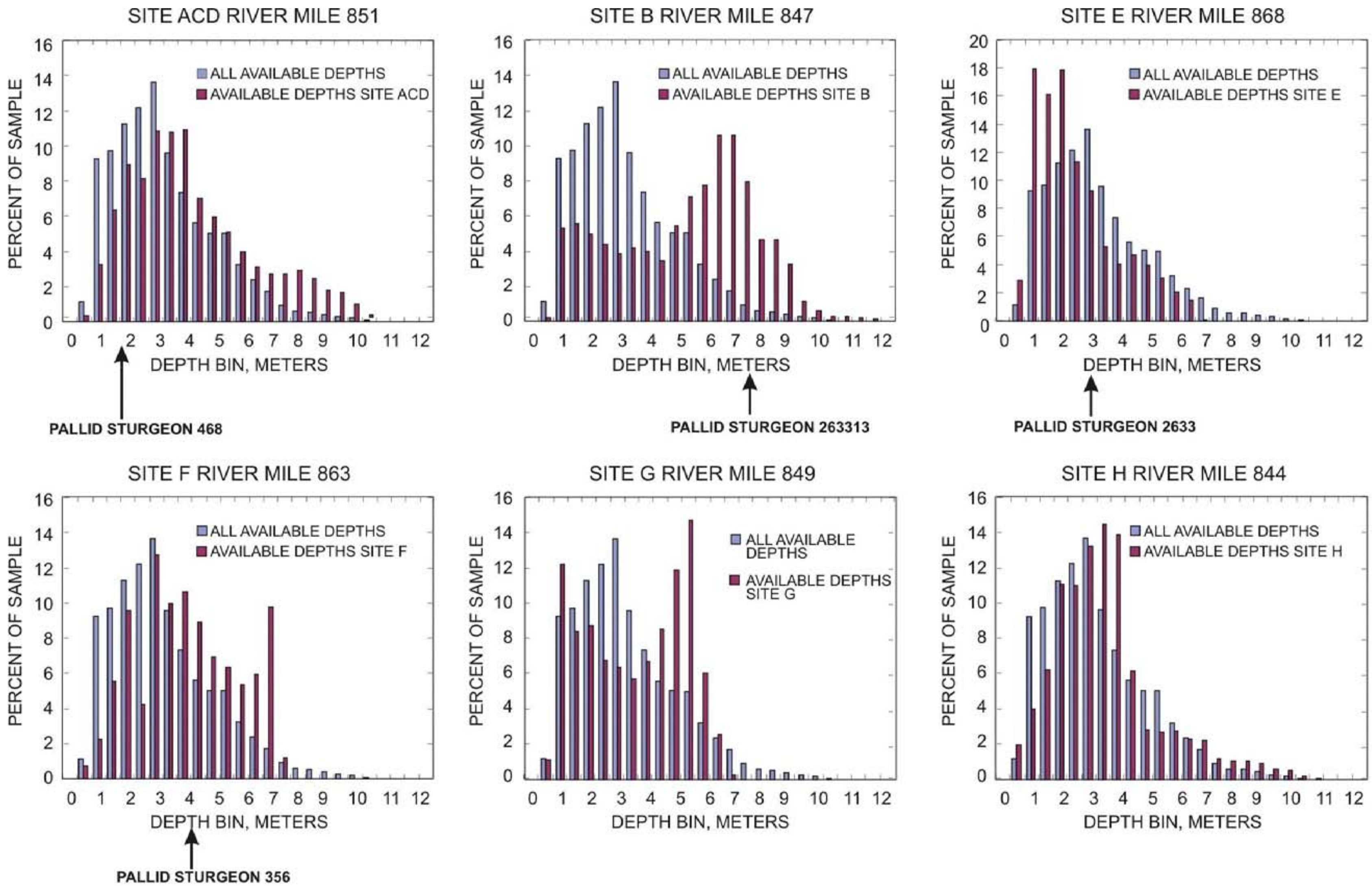


Figure 14. Histograms of depth ranges at habitat assessment sites acd through h binned in 0.5 m depth classes. A histogram of all measurements made in this study is included in each plot for reference. Stars indicate depth bin selected by fish at a specific site.

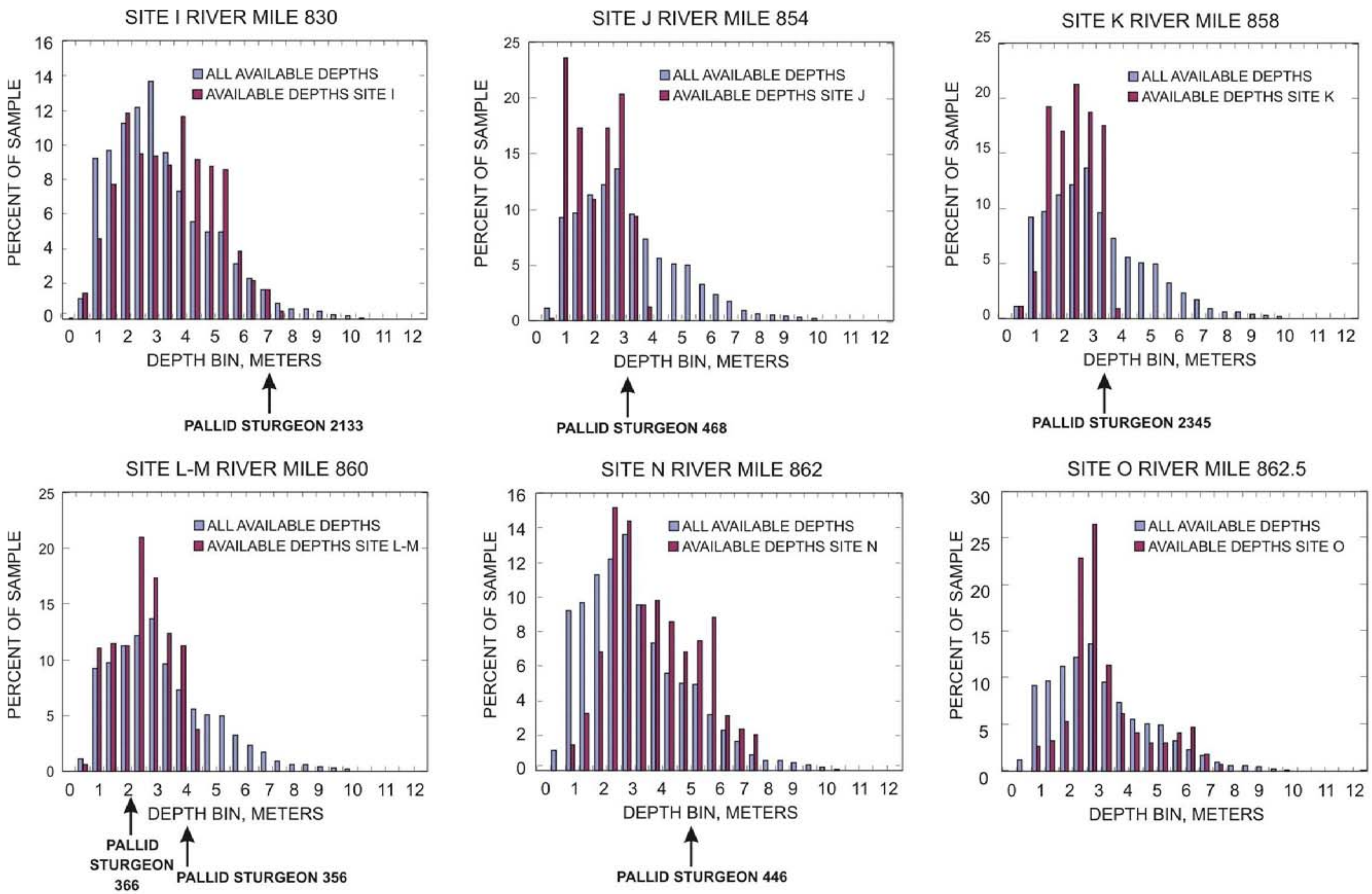


Figure 14 (continued). Histograms of depth ranges at habitat assessment sites i through o binned in 0.5 m depth classes. A Histogram of all measurements made in this study is included in each plot for reference. Stars indicate depth bin selected by fish at a specific site.

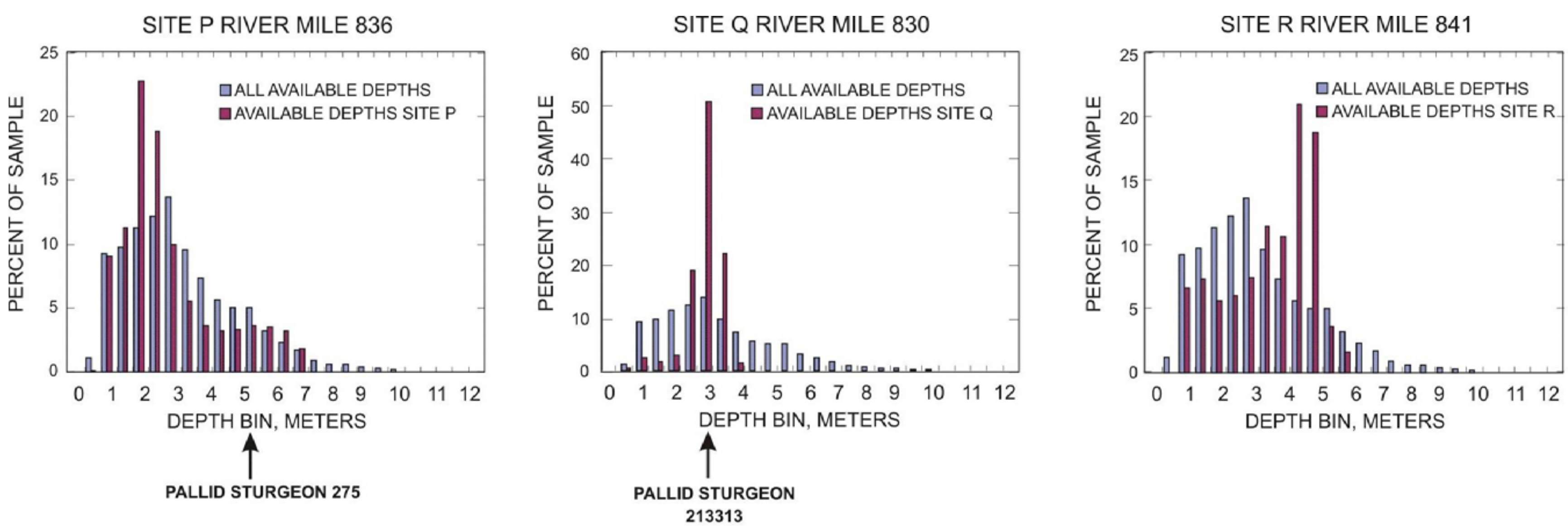


Figure 14 (continued). Histograms of depth ranges at habitat assessment sites p through r binned in 0.5 meter depth classes. A histogram of all measurements made in this study is included in each plot for reference. Stars indicate depth bin selected by fish at a specific site.

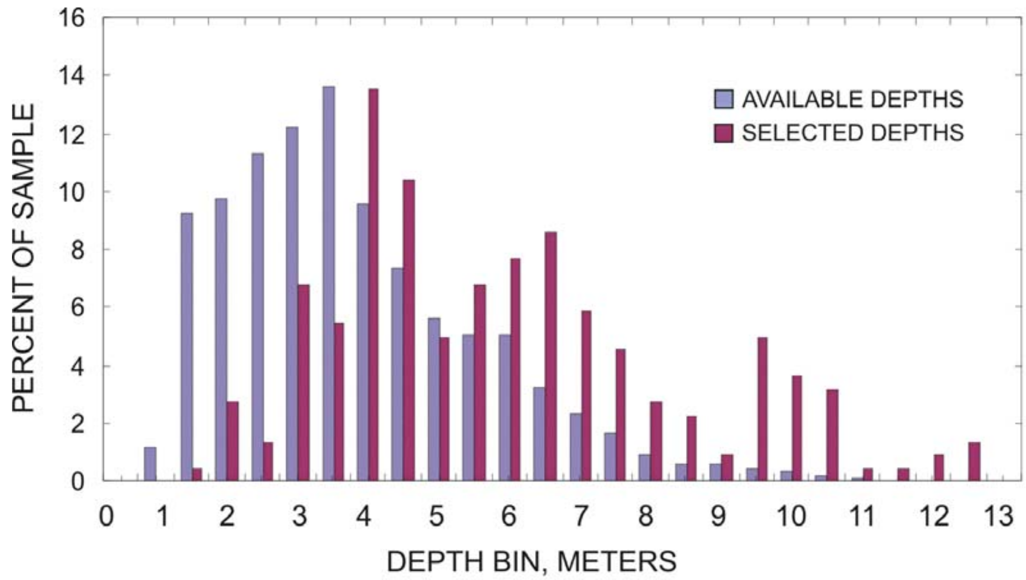


Figure 15. All measured habitat assessment depths representing available habitat in the Fort Randall segment. Fish location histograms indicate selected depths within 5 meters of a fish location for all fish measurements made at discharges between 20,000 and 32,000 cfs.

Velocity

The general range of depth-averaged velocities measured at habitat assessment sites is 0 – 252 cm/sec (table 3). Mean depth-averaged velocities vary by site between 70 and 101 cm/sec. Histograms in figure 16 show ranges in velocities binned by 10 cm/sec intervals by site plotted with the distribution of velocities for all sites for reference. Velocity data show a normal distribution.

Regions of higher velocity are associated with the channel thalweg and regions connected to the main flow of the river. Eddies and shallow sandbar regions are associated often with slow and recirculating upstream flow. Site velocities are fairly homogenous at site Q, the furthest downstream site, located in the headwaters of Lewis and Clark Lake (fig. 16).

Point velocities for pallid sturgeon locations measured by USFWS and this habitat assessment are summarized in table 3. Similar to depth data, large variation in velocity may occur within the spatial accuracy range of the telemetry equipment, so single-point values can be misleading. Also, USFWS velocity data were averaged from data collected at 0.2 and 0.8 percent of the depth whereas USGS ADCP data were calculated as depth-averaged values for single ensembles. Within the USGS dataset, pallid sturgeon used velocities ranging from 69 – 101 cm/sec in habitat assessment sites. The spatially averaged velocity at the 12 pallid locations was 88 cm/s. Most fish location velocities are within the range of average velocities available for a given site (fig. 16). A histogram of all telemetry measurements within a similar range of discharges and falling within habitat assessment regions is compiled in figure 17. The majority of these measurements fall between 40-130 cm/sec. Pallid sturgeon in the Fort Randall segment generally use velocities in the same proportion as their availability. This could be interpreted as indicating no selected preference, or that available velocities in the Fort Randall segment are optimal for this species and there is no motivation to select among them.

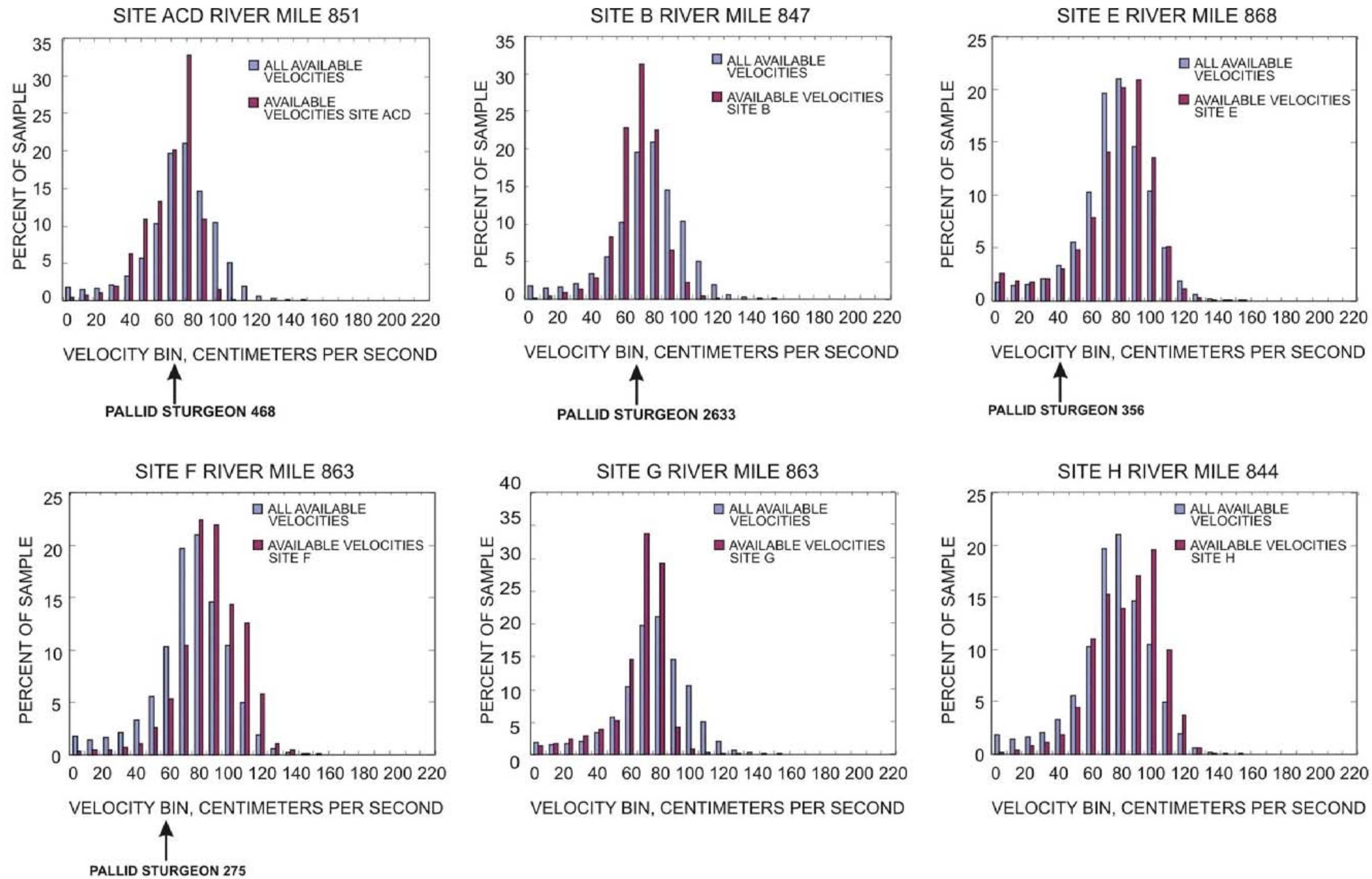


Figure 16. Histograms of depth-averaged velocity ranges at habitat assessment sites acd through h binned in 10 centimeter per second classes. A histogram of al depth averaged velocity measurements made in this study is included in each plot for reference. Stars indicate depth averaged velocity bin selected by fish at a specific site.

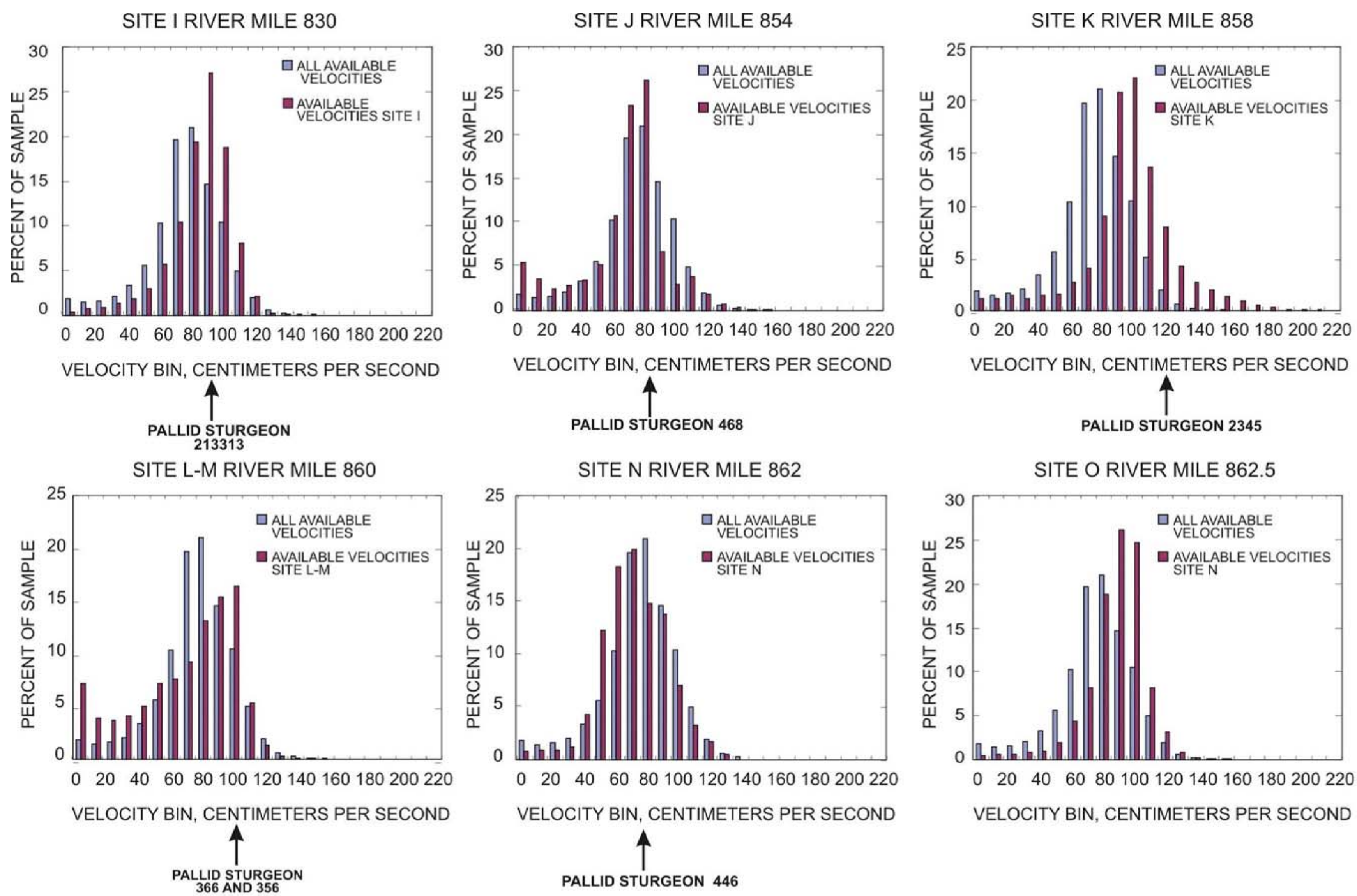


Figure 16 (continued). Histograms of depth-averaged velocity ranges at habitat assessment sites i through o binned in 10 centimeter per second classes. A histogram of al depth averaged velocity measurements made in this study is included in each plot for reference. Stars indicate depth averaged velocity bin selected by fish at a specific site.

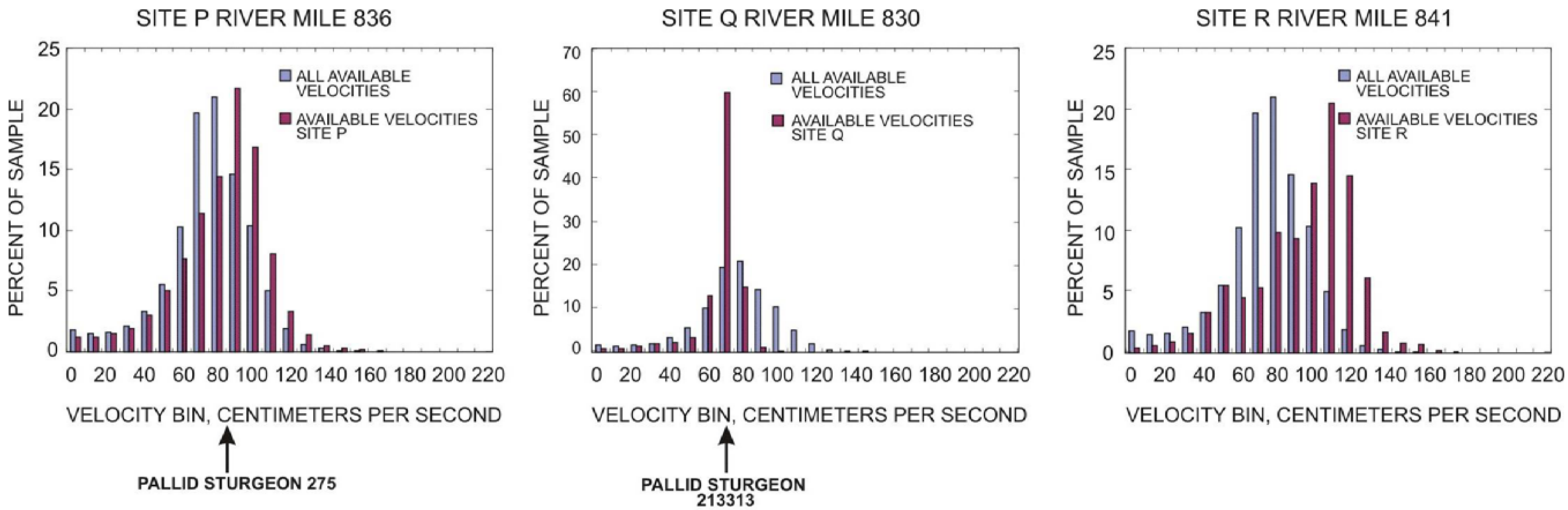


Figure 16 (continued). Histograms of depth-averaged velocity ranges at habitat assessment sites p through r binned in 10 centimeter per second classes. A histogram of al depth averaged velocity measurements made in this study is included in each plot for reference. Stars indicate depth averaged velocity bin selected by fish at a specific site.

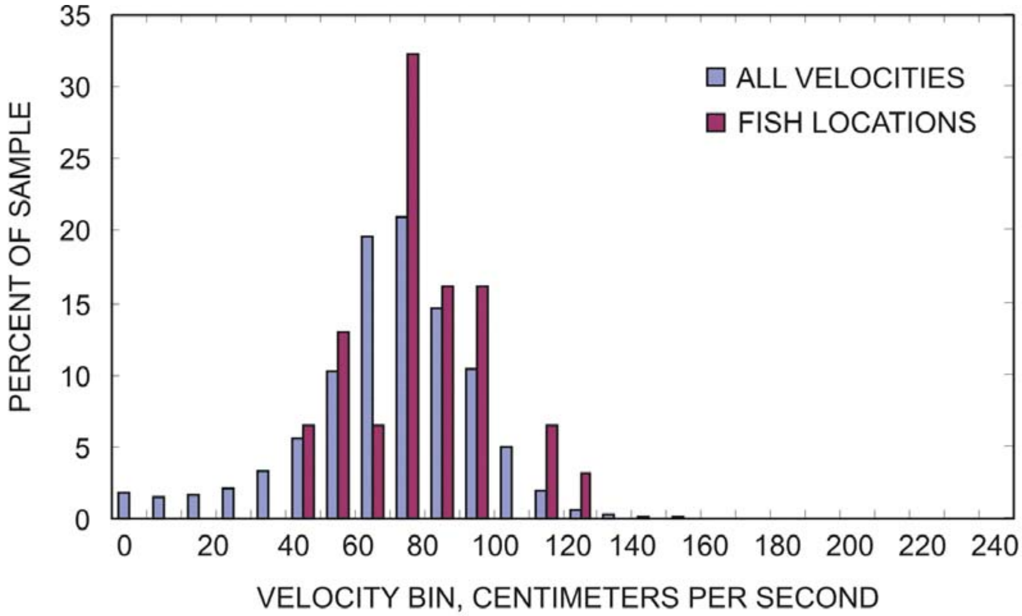


Figure 17. All average velocity measurements for habitat assessment representing available habitat in the Fort Randall segment. The fish locations represent the velocities selected by pallid sturgeon within the mapped regions at discharges between 20,000 and 32,000 cfs

Substrate

An unsupervised multivariate classification of roughness (e1), hardness (e2), and depth values yielded four distinct classes (fig. 13, and maps in appendix). The mud/silt/fine sand with vegetation class was found in shallow, near shore regions where submerged aquatic vegetation could grow as a result of light infiltration. This class had the softest hardness values and medium to high roughness values. The second class of sand and small dunes was generally found in deeper water, was relatively soft, and was less rough than other classes. Sand and vegetation, the third class was rough, hard, and shallow. The fourth class was rough, relatively hard, and found in the deepest channel segments. USGS sidescan sonar data indicates these regions to be sandy with large (5-10 meter scale) dunes.

Pallid Sturgeon habitat use compared to habitat availability becomes apparent when viewing results of fish locations. There is considerably more area available in the mud/silt/fine sand and vegetation class than is used (fig.18). Approximately one third (30%) of the total mapped area segregated out in the mud/silt/fine sand with vegetation class whereas only 11% of the fish locations occur within this unit. Fish appear to select sites with open sand with large dunes over any other substrate, and tend to prefer sandy substrates overall, with 41% of the fish locations occurring on the open sand with large dunes unit.

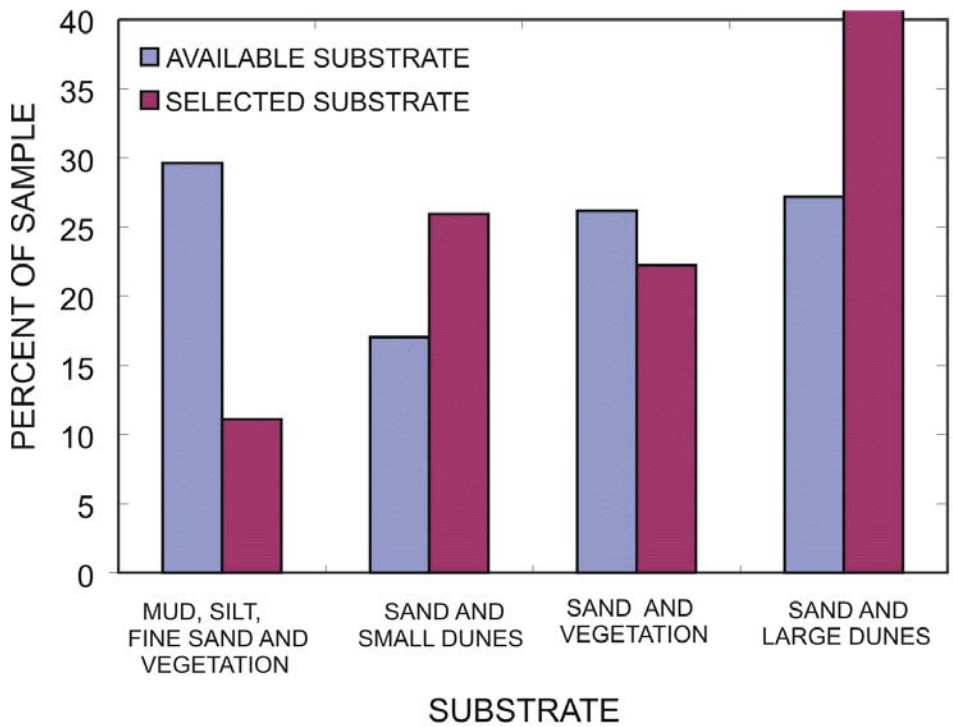


Figure 18. Total available substrate and selected substrate for Pallid sturgeon locations in the Fort Randall segment.

Sidescan sonar

A typical sidescan image is detailed in figure 17. The image shows the sonar record using both channels (left and right) at a range of 20 meters (total swath width of 40 m). The bright line in the center of the image corresponds to the track of the towfish and the source of the acoustic signal. The dark band adjacent to the acoustic signal pulse is the water column beneath the side-looking towfish. This dark area is roughly equivalent to the height of the towfish above the bottom. The sonar record shows the reflected backscatter from the bottom, as well as any objects lying on the bottom or in the water column (for example, fish, tires, wood). Images in this report have been formatted to display highly reflective objects (rocks, fish) as bright areas and soft, non-reflective surfaces as dark areas.

There are some limitations to this system as deployed. It is primarily designed as an imaging system, as opposed to a mapping system. The towfish itself is not instrumented and cannot compensate for heave, pitch or roll. Significant wave action, erratic navigation, complex water currents and turbulence, and operation in very shallow water may adversely effect the stability of the towfish resulting in image distortion or aberrations. These artifacts are not correctable through post-processing. The system must also be operated in more-or-less a straight line. Straight-line imaging is difficult in many shallow water environments.

Initial surveys were hampered by high winds and towfish instability. The towfish was modified with a new tailfin assembly and the addition of a depressor. Software improvements also significantly increased the dynamic range of the imagery for later surveys. Equipment failure caused by extreme cold temperatutes prematurely ended side-scan survey efforts midway through the October survey period. Example images of bottom types and features imaged during this survey are found in figs. 19-28.

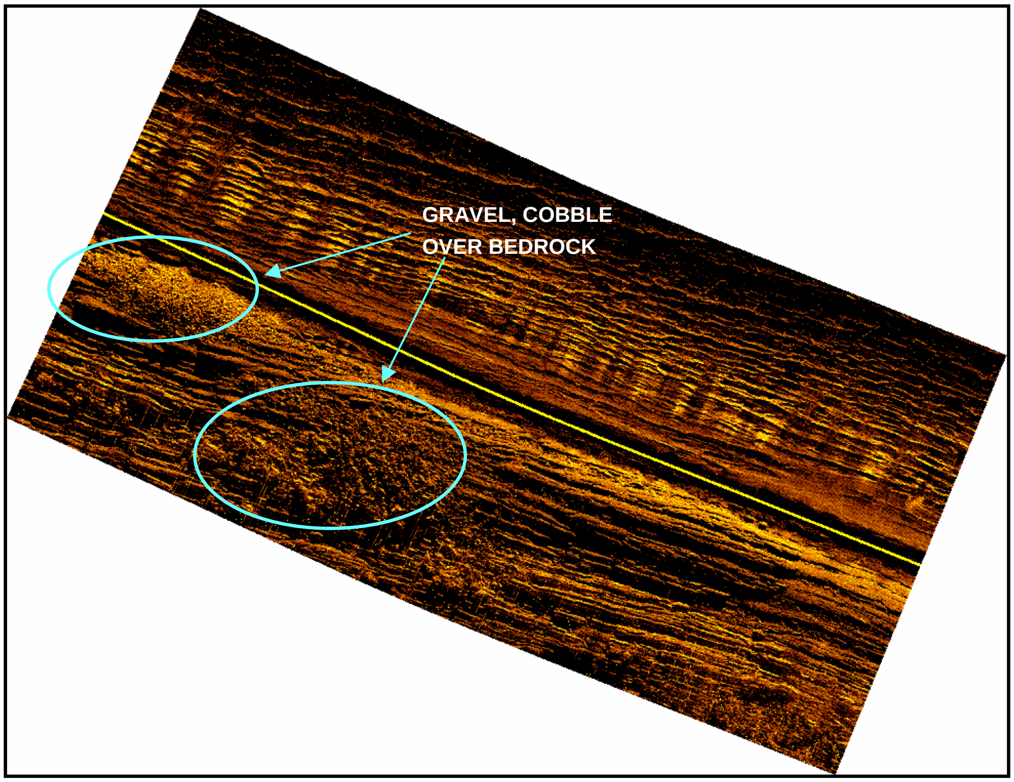


Figure 19. Sidescan imagery of bedrock, and bedrock overlain by gravel and cobble. Imagery collected at Site L-M, RM 860 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

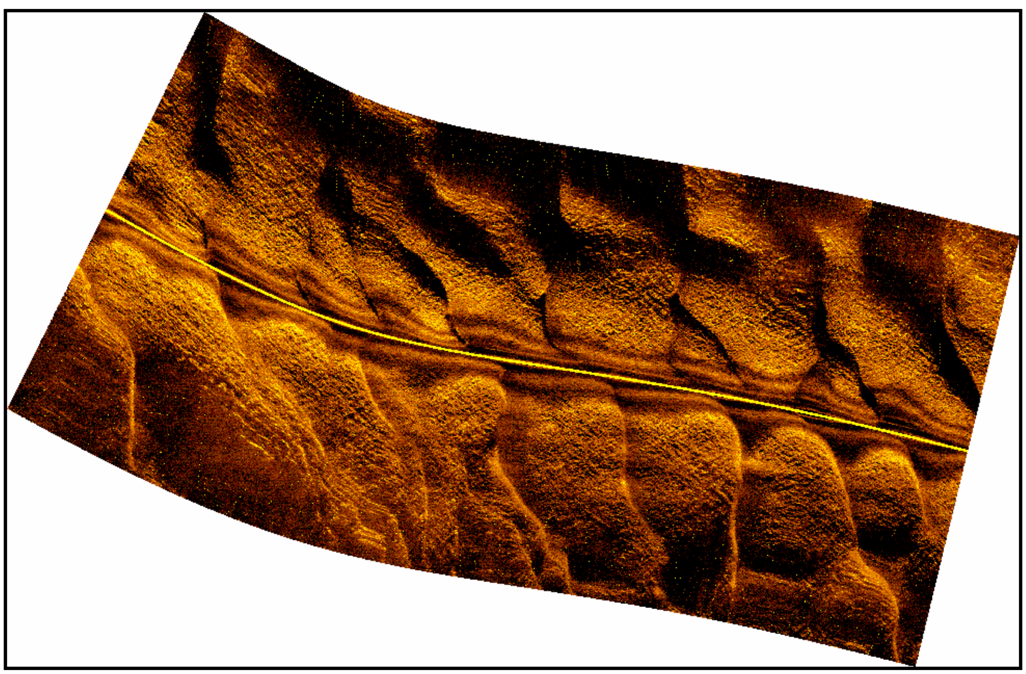


Figure 20. Sidescan imagery of large, periodic sand dunes at the bottom of the Missouri River. Imagery collected at Site K, RM 858 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

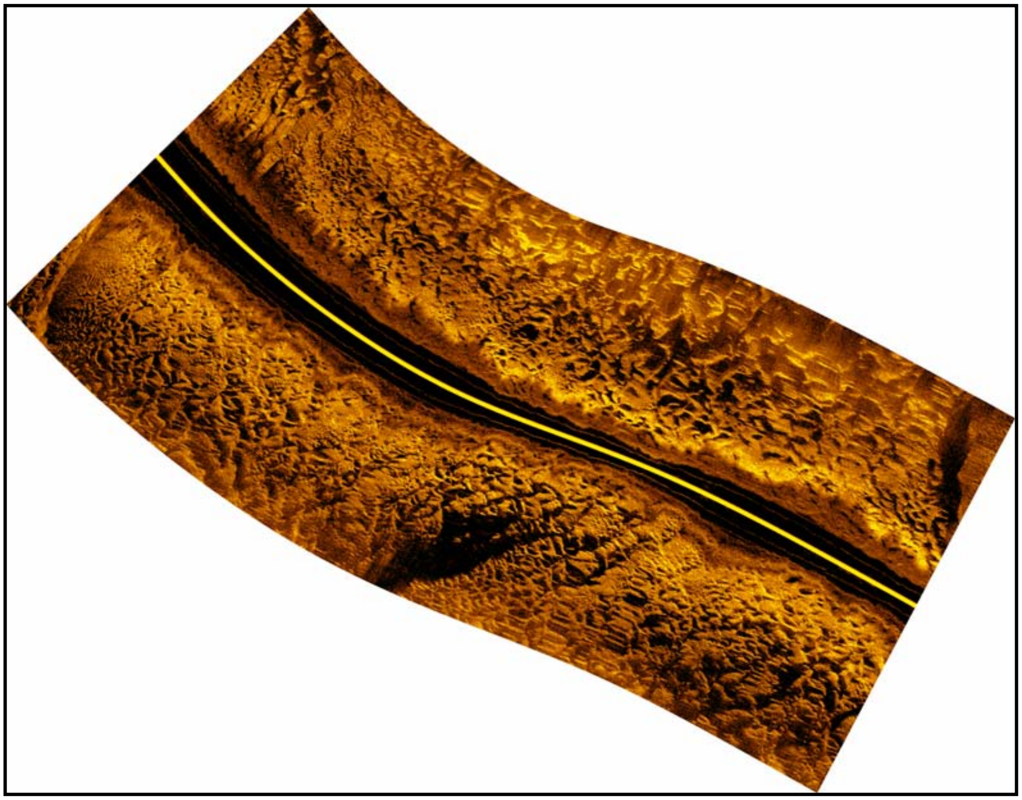


Figure 21. Sidescan imagery of small, irregular sand dunes at the bottom of the Missouri River. Imagery collected at Site L-M, RM 860 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

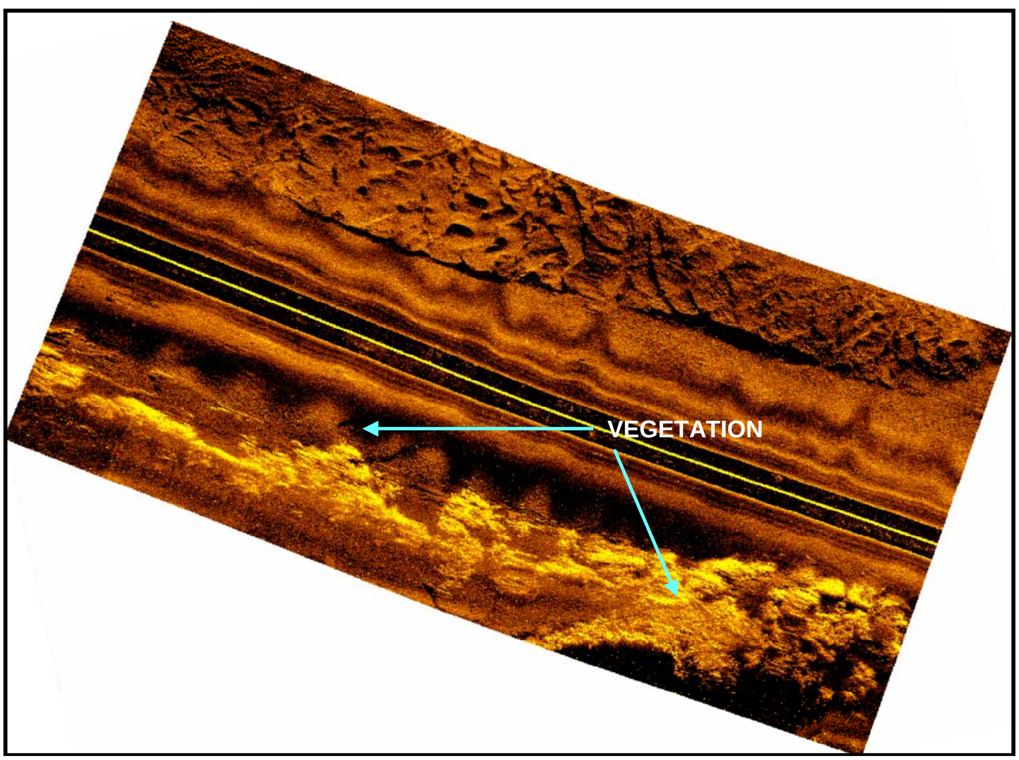


Figure 22. Sidescan imagery showing aquatic macrophytes (bright, highly reflective patches in the lower left margin), small, irregular sand dunes (upper right margin), and soft, fine sediment (middle). Site J, RM 854 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

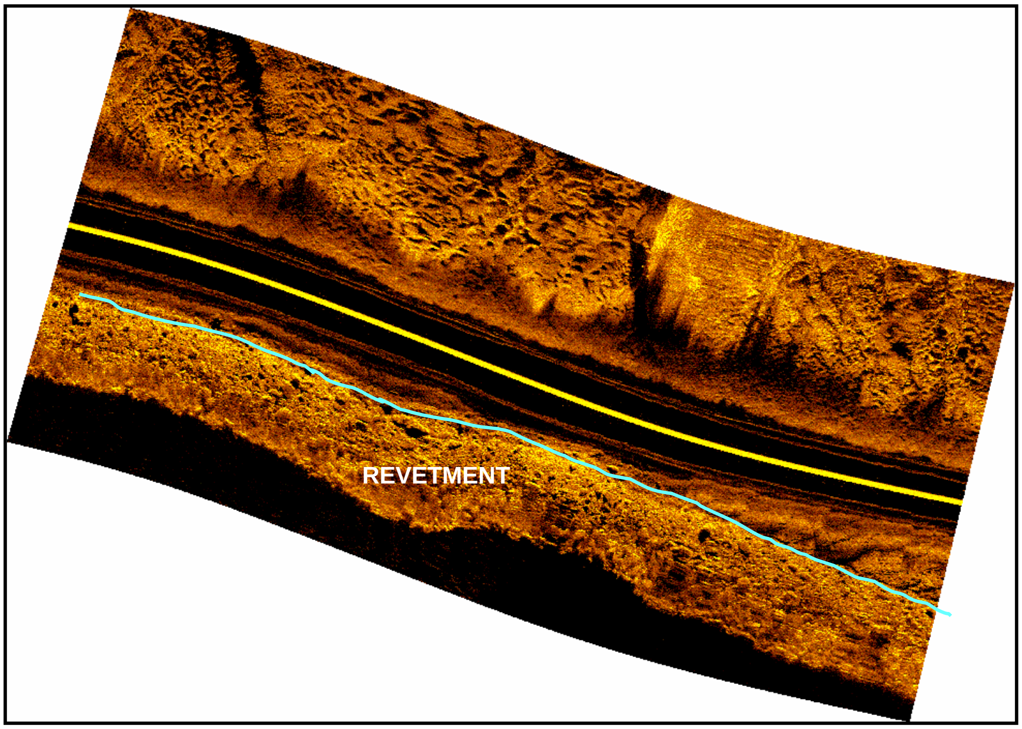


Figure 23. Sidescan imagery of bank revetment. The lower margin of the image is lined by coarse material typically used for bank revetment. The bottom adjacent to the revetted bank is dominated by small, irregular sand dunes. Imagery collected at Site E, RM 868 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

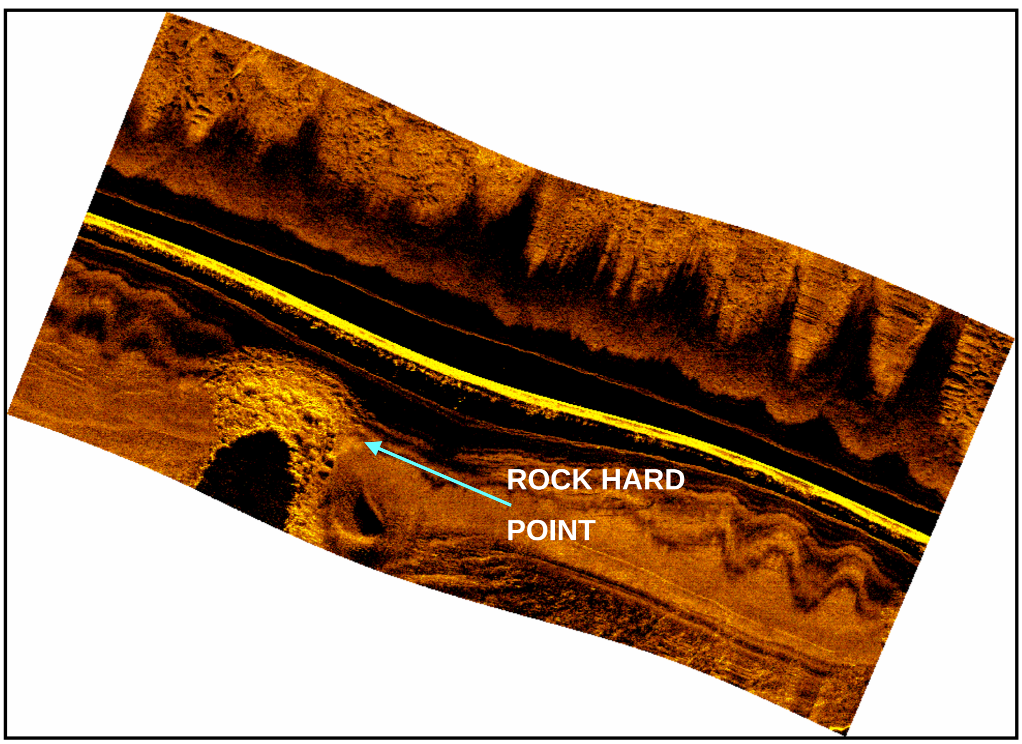


Figure 24. Sidescan imagery of a constructed hard-point. Imagery collected at Site E, RM 868 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation.

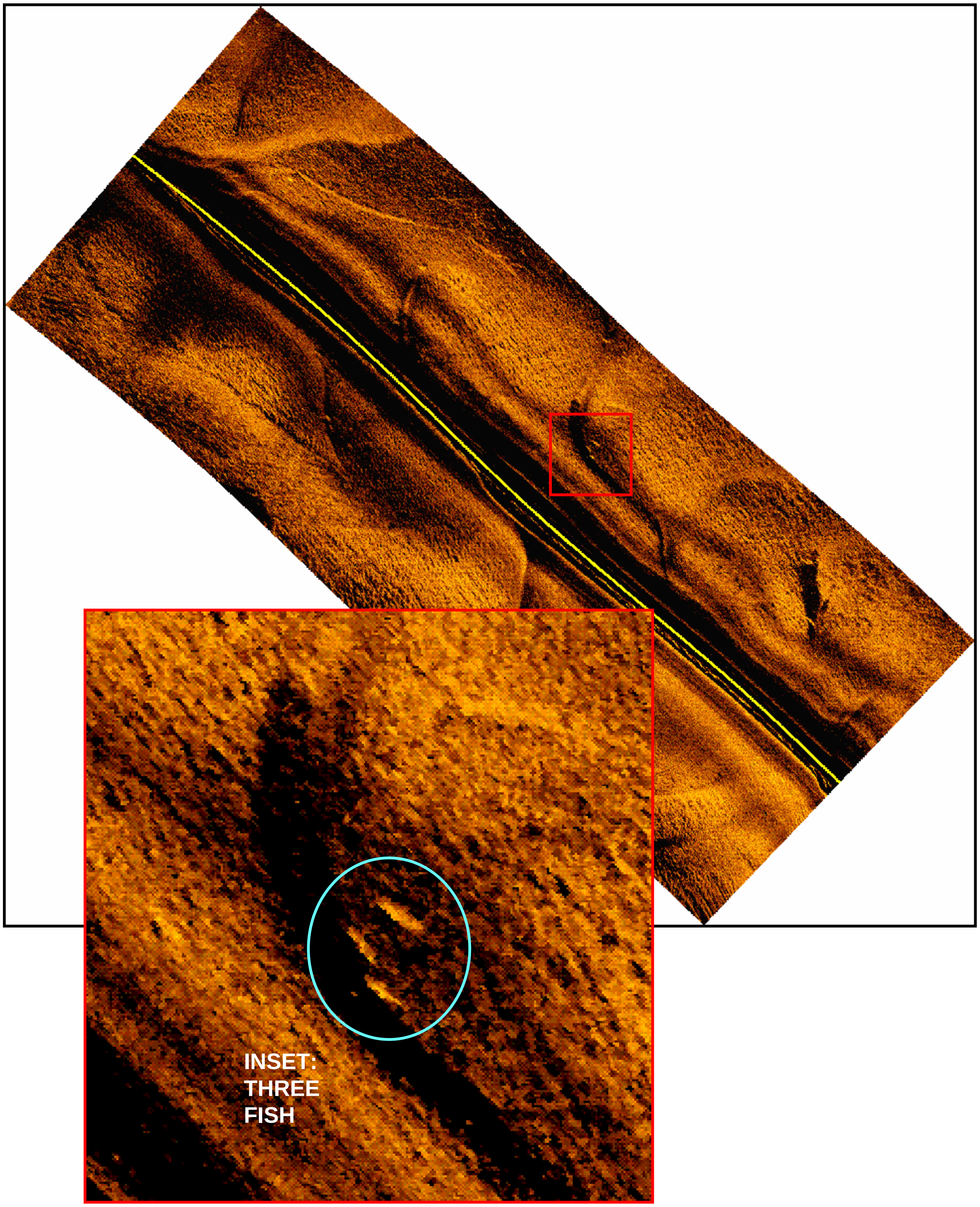


Figure 25. Sidescan imagery of large, periodic dune field with large fish (0.5 – 1.0 m) occupying dune margins. Imagery collected at Site K, RM 858 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation

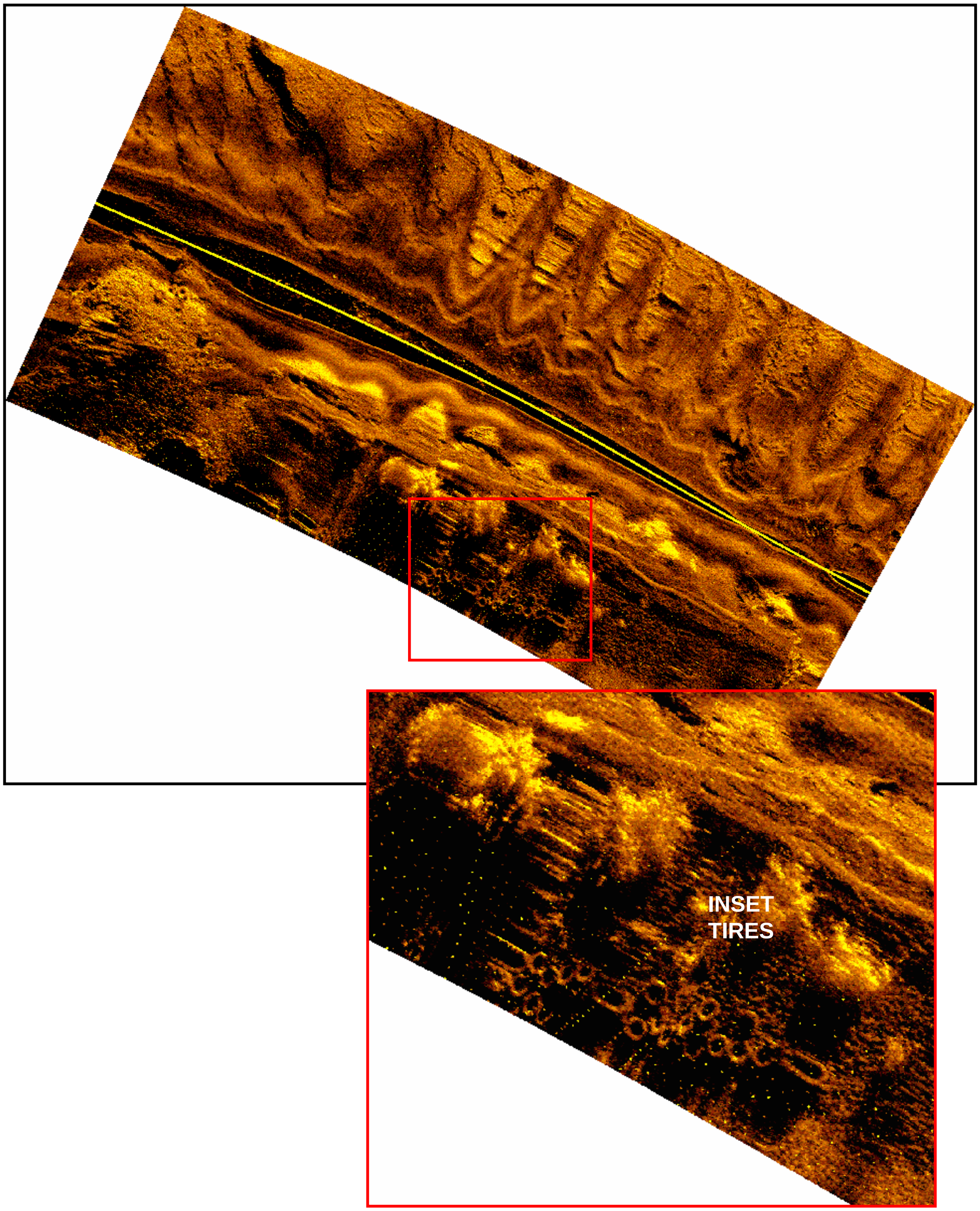


Figure 26. Sidescan imagery showing large numbers of vehicle tires. Imagery collected at Site J, RM 854 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation

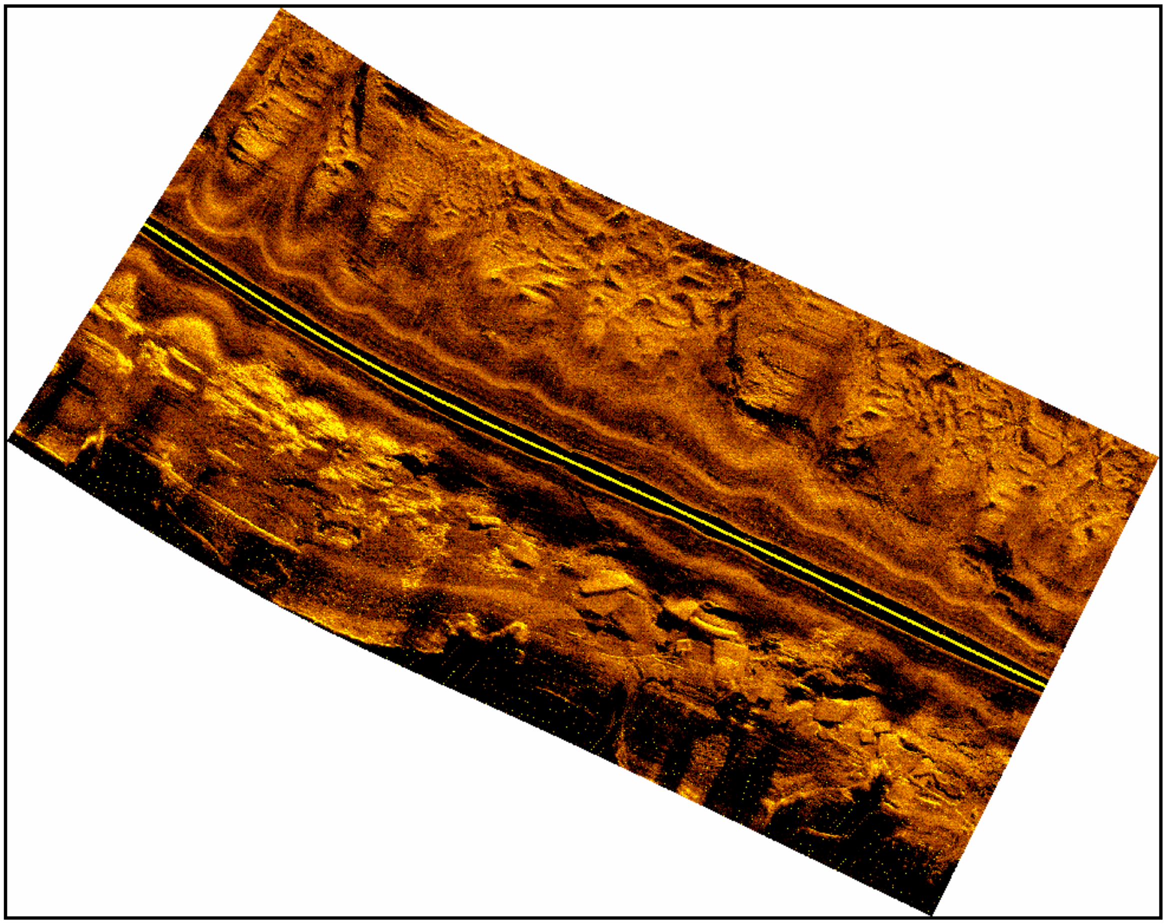


Figure 27. Sidescan imagery showing large concrete slabs. Imagery collected at Site J, RM 854 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation

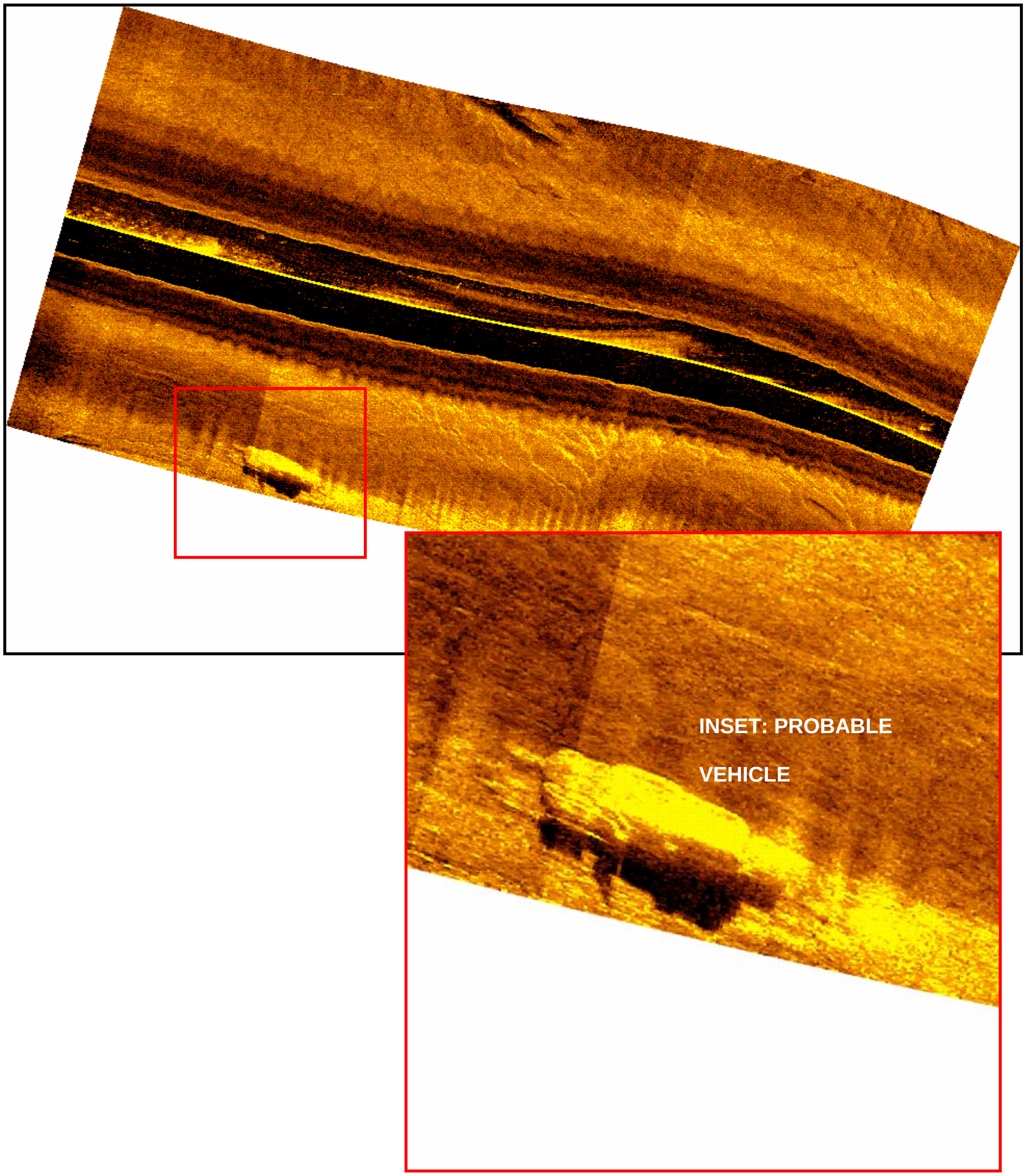


Figure 28. Sidescan imagery showing probable submerged vehicle. Imagery collected at Site ACD, RM 851 with a 900 kHz towfish (20-m range). Imagery has been georeferenced and corrected for navigation

Conclusions

This study addressed habitat availability and use by endangered pallid sturgeon (*Scaphirhynchus albus*) in the Fort Randall segment of the Missouri River. Physical aquatic habitat – depth, velocity, and substrate – was mapped in 15 sites in August and October of 2002 during flows that were representative of summer-fall navigation season releases. Habitat assessments were compared with fish locations using radio telemetry. Results indicate that pallid sturgeon preferentially use locations in the Fort Randall segment with deeper than the average available habitat. There were multiple depth usage peaks at 3.5-4.0 m and 6-6.5 m, compared to the mode of availability at 3-3.5 m. The fish use habitats with a modal velocity of 80 cm/s. The distribution of used velocities is nearly identical to the distribution of available velocities, indicating little preference. Fish located preferentially over sand substrate with large and small dunes, and seemed to avoid mud and submerged vegetation.

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